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The Association

AGRICULTURAL AND CHEMICAL SERIES. BULLETIN No. 34

REPORT OF WORK
OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

Some Bio-Chemical Investigations of Hawaiian Soils,

With Special Reference to Fertilizing with Molasses.

BY S. S. PECK

HONOLULU, HAWAII.
SEPTEMBER, 1910.

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LETTER OF TRANSMITTAL.

To the Experiment Station Committee of the
Hawaiian Sugar Planters' Association,
Honolulu, Hawaii.

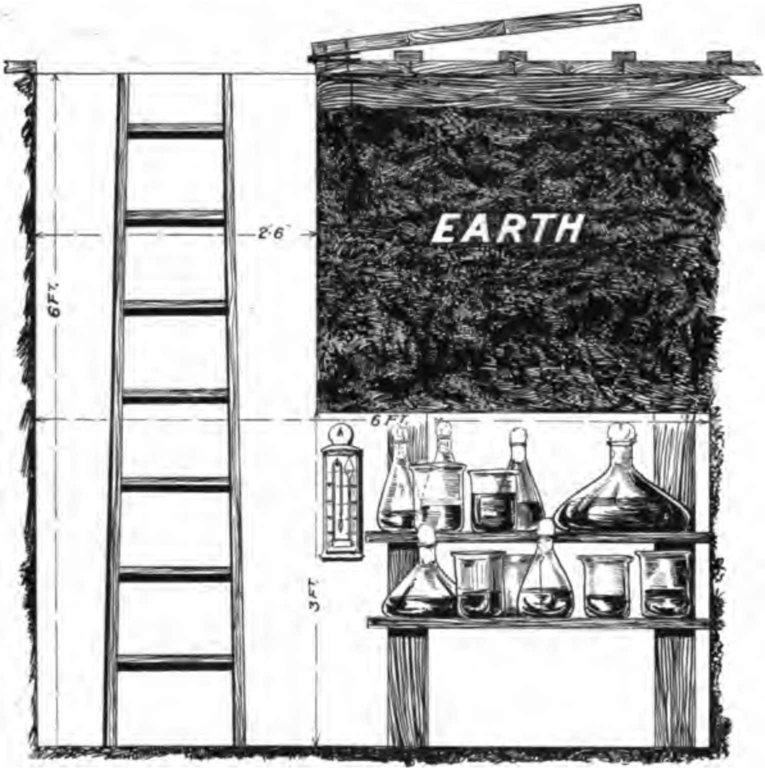
Dear Sirs:—I herewith submit for publication as Bulletin No. 34 of the Agricultural and Chemical Series, an article by Mr. S. S. Peck, Chemist, entitled: "Some Bio-chemical Investigations of Hawaiian Soils with Special Reference to Fertilizing with Molasses."

Yours very truly,

C. F. Eckart,

Director.

Honolulu, Hawaii, September 22, 1910.


EARTH
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UNDERGROUND CULTURE CHAMBER.

(See Page 16.)

SOME BIO-CHEMICAL INVESTIGATIONS OF HAWAIIAN SOILS, WITH SPECIAL REFERENCE TO FERTILIZING WITH MOLASSES.

By S. S. Peck.

It is only about three decades since the application of bacteriological investigation has been vigorously followed as regards agriculture and soil investigations. Following Liebig's conclusions, the soil was presumed to be but a storehouse of nutrients for the growing plants, and an exhausted soil implied principally a lack of mineral nutrients. According to Liebig, the nitrogen was supplied to plants from the ammonia brought to the soil in the rain water, and derived from the air. When confronted by figures showing the small quantity of nitrogen thus introduced into the soil, amounting to only a few pounds annually, he maintained that the plants, particularly cereals, were able to take ammonia directly from the air through their leaves. To him, as well as many other early investigators of soil problems, the changes taking place in the soil were of a purely chemical nature.

The first impetus to the bacteriological examination of soils was received from Pasteur's investigations and results in other fields of bacteriological research. It was he, also, who first suggested that nitrification in soils was due to ferments, and also called attention to the fact that micro-organisms, aside from those whose actions are injurious or pathogenic, are indispensable for the continuance of life, both vegetable and animal. He wrote: "If the micro-organisms disappeared from the earth, the surface of the globe would be filled with dead organic matter and dead bodies of all kind, animal and vegetable. It is principally to them that oxygen owes its consuming properties; without them, life would become impossible, since the work of death would be incomplete "[1]

Since the inception of bio-chemical soil investigations, the nitrogen problem has absorbed the attentions of soil bacteriologists almost exclusively. Some work has been done as regards the action of soil bacteria on phosphorus and potassium compounds in the soil, but to a very limited extent. The recognized dependence of the plant kingdom on the nitrogenous nutrients available, the limited supply of nitrogenous fertilizers, and their greater money value as compared with those supplying phosphorus and potassium, have all tended to divert the channel of soil bacterial investigation in this direction.

The first actual experimental proof of the process of nitrification in soils was recorded by Schloesing and Muntz in 1879.[2] On passing sewage rich in ammonia and nitrogenous compounds through a soil filter, they observed that the water draining through was much richer in nitrates than that entering. On first treating the soil filter with antiseptics, the transformation was stopped; and others afterwards demonstrated that heating the soil produced the same effect as that from antiseptics. They therefore concluded that the changes were bacterial in their nature, but their views were not accepted at once, for as late as 1887 investigators are found still clinging to the chemical theory of nitrification. It was not until after the extensive researches of Warington and Frankland, and finally the isolation of the specific organisms causing the nitrification, by Winogradsky in 1890, that the bacterial theory became firmly grounded.

The biological viewpoint of the soil has now become as thoroughly accepted as was the chemical some decades ago. The soil can no longer be looked upon as a non-living mass merely furnishing a mechanical support to roots of plants and acting as a carrier of moisture and dissolved nutrients to them. All the improvements from the usual practices of good husbandry, such as cultivation, drainage, fertilization, green manuring, etc., are largely explainable by their respective and collective beneficial actions on the teeming millions of micro-organisms inhabiting the soil.

The soil can be regarded from several viewpoints, a recent publication [3] dividing them into, 1. Physiographical (regarding origin); 2. Chemical (as a purveyor of plant food); 3. Physical or mechanical (as a medium for the transmission of moisture and plant food); and 4. Biological, from which viewpoint "a soil is a more or less weathered rock detritus commingled with organic matter, wherein micro-organisms, mostly bacterial in their nature, functionate, transforming raw materials into available plant food, reducing relatively complex molecules of animal and vegetable origin into simpler forms suitable to plant nutrition." Soil fertility, which to the chemists means the maintenance in the soil of conditions necessary for providing the necessary mineral nutrients or their introduction therein from artificial sources; to soil physicists, the optimum mechanical conditions suitable for root development, drainage, and moisture conservation; to later investigators, the elimination of toxic excretions from the growing crop, means to the soil bacteriologist the maintenance of those conditions of drainage, aeration, nutrition and reaction which will react most favorably on the development of beneficial soil organisms, and the introduction into the soil, when necessary, of such organisms as are essential to the growth of particular plants.

Bacteria are divided into two general classes; aerobic, or air-loving, and anaerobic, or those developing only in the absence of air. Between these two classes are found those which can adapt themselves to either condition, termed facultative aerobic or anaerobic. Again, both types may flourish together, the aerobic, by withdrawing the oxygen from the soil air furnishing a suitable atmosphere for the anaerobic organisms. In agriculture, however, the conditions of tilth furnish the conditions best suited for aerobic bacteria, and for the purposes of soil investigation these are the only ones requiring close study.

As long ago as 1850 it was a matter of common knowledge that crops of the leguminosae family contained more nitrogen than was supplied to them as fertilizer or removed from the soil, but it was not until 1886 that the researches of Hellreigel and Wilfarth established the connection between this increase and the symbiotic fixation of nitrogen from the atmosphere by the plant and bacteria found in the nodules of the roots, named *Pseudomonas radicicola.* [4] The final test of the presence and activity of these organisms in a given soil is the development of the characteristic tubercles on the roots of a plant of this family when growing in the soil, and this does not come strictly within the scope of a biochemical examination of the soil. In connection with these particular organisms, it has been found that when the leguminous plant has failed to develope the root-nodules, other conditions such as tilth, reaction, etc., of the soil being favorable, the absence of the bacteria peculiar to the host plant is demonstrated. The soil can be then inoculated either by the necessary pure culture of the organism needed; or better, by supplying the organism by adding soil from a region where the successful development of the plant in question has shown the presence of the desired organism.

In reference to other bacteria of the soil, however, the problem of inoculation has not yet been worked to a successful conclusion. As a matter of fact, all the organisms necessary for the transformation of nitrogen in the soil are present, in varying numbers and proportions, in all arable soils. Their numerical or potential proportions, however, as well as the correct conditions of moisture, temperature, chemical and mechanical conditions of the soils, and the presence of larger organisms, are not always favorable to the development of the most beneficial species. It is by altering or assisting these conditions that the present status of the chemico-bacteriological investigations of soils can serve its most useful purpose toward agricultural economy. Additions of antiseptics, such as carbon bisulphide, thorough aeration and exposing to the heat of the sun, and burning off the surface of fields have produced favorable crop results which can be largely attributed to changes in the bacterial flora of the surface soil. Improving the drainage; altering the mechanical condition of the soil by addition of such amendments as lime, lime carbonate, or gypsum; correcting soil acidity by lime salts; increasing the humus content of the soil by plowing under green crops or addition of stable manure; addition of fertilizers supplying necessary mineral nutrients,—all find a partial answer as to the reason of increased crop returns in their respective effects on the beneficial organisms of the soil.

In the beginning of this year, work was initiated at this Station with the intention of investigating the bacterial action in Hawaiian soils, with the idea of establishing a basis from which the fertility of the soils might be measured in terms of transformation of nitrogen compounds; and also with the view of isolating the predominant bacterial species, studying their action in pure culture, and establishing their identity, when possible, with species already described. At about this time our attention was called to the use of molasses as a fertilizer, and a series of experiments was started to determine the action of molasses on the various soil organisms as respects their transformation of nitrogenous fertilizers.

Molasses has been used as a fertilizer on cane fields with varying results. In 1903, the Java Experiment Station, having its attention called to the uncertain results from this use of waste molasses, undertook a series of field experiments. [5] In the first series, molasses was applied to growing cane in the furrow at the rate of five gallons per furrow* with the result that the cane died after two days. In another series the cane received molasses partly dissolved in the irrigation water at the rate of 350 cubic centimeters per plant, or 7 liters per furrow, these plats and the check plants receiving a further dressing of sulphate of ammonia at the rate of 133 pounds per acre. The results of the molasses plats and two others receiving no molasses were:

	Molasses.	No Molasses.	
Tons cane per acre	34.65	34.32	37.29
Tons available sugar per acre	4.58	4.75	5.04

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*The original article gives the measurements of molasses in "kerosene tins," which I have presumed to have a content of 5 gallons each.

In the same year new tests were started, where, instead of applying the molasses to the growing cane, it was poured on the ridge hilled up between the furrows. After a month the furrows were filled up to a depth of seven inches with soil and fertilized with bean cake at the rate of 22 pounds of nitrogen per acre. After planting, the plats were fertilized with 133 pounds of sulphate of ammonia per acre, and cultivated the same as the check plats. Two plats received 5 gallons molasses per furrow, and two received 10 gallons. The results were as follows, in tons of cane and sugar per acre.

	Cane.	Sugar·	Cane.	Sugar.
No molasses	21.58	3.13	25.18	3.64
5 gallons molasses	21.58	3.04	28.05	4.04
No molasses	21.95	3.08	25.54	3.94
10 gallons molasses	22.67	3.14	28.41	4.04

These results show a very slight difference in favor of molasses, which is not beyond the errors of observation.

In 1909 there were reported results from the experiment station in Mauritius[6] where decidedly increased gains were obtained when a liter of molasses was placed in each cane hole at the time of digging them, two months previous to the planting of the seed cane. The increased yield persisted, although to a greatly diminished extent, to the third ratoon crop. The author is inclined to ascribe the beneficial action of the molasses to something besides the fertilizing ingredients contained therein; and suggests a possible advantage in employing it in small doses in diluted condition, frequently repeated. This statement is quite contrary to the experience obtained in Java, and as will be seen from the tests carried on in this laboratory, not to be accepted for Hawaiian conditions.

During the season of 1908-1909, a series of molasses fertilizing experiments were concluded at Antigua.[7] Second vacuum pan molasses was used at the rate of 200 and 400 gallons per acre to ratoon cane, about six weeks after the canes had been cut as plant, it being applied proportionately at the rate required to each cane hole. The plots were 1-40 acre in area, and formed an adjunct to a larger series of manurial experiments carried on at various estates. Five estates reported results, of which four gave an increased yield due to the molasses, and one a loss. The average of all five was: No molasses, 8.7; 200 gallons molasses 10.0; and 400 gallons molasses, 11.7 tons per acre. The maximum gain was 7·7 tons cane per acre, from 400 gallons; the minimum gain, 1.8 tons from 400 gallons; and the greatest loss was 3.2 tons from 200 gallons. The greatest increase of yield was not remunerative at the price that molasses was bringing at that time. The author is of the opinion that the increase of yield could not be ascribed to the potash in the molasses, since an average of five years experiments shows that an application of 60 pounds of potash without nitrogen or phosphoric acid increased the yield over the no-manure crops by only 0.7 ton cane per acre. The nitrogen and phosphoric acid in the molasses were in too small amounts to have affected the yield. The differences, however, in our opinion, are too slight to lead to any definite conclusions. Thus in another test completed this same year, a series without manure gave 15.1 tons per acre, and one with 60 pounds of potash as sulphate yielded 18.4 tons, or a gain of 3.3 tons; on the other hand, plots receiving 60 pounds of nitrogen as sulphate of ammonia and 40 pounds of phosphoric acid, show generally a small loss when potash was supplied in addition. The average gain in the molasses test was 3 tons of cane per acre from 400 gallons of molasses, which is the same as that due to 60 pounds of potash in experiments carried on during the same season.

In 1909 the Java Experiment Station [8] reported results from six localities on the use of molasses as fertilizer. The general plan of the experiments was as follows:—A section of land was divided into 40 subdivisions, each comprising from 25 to 50 furrows, and treated in the following manner·

1. 5 gallons* molasses in the furrow, and 5 gallons on the ridge.
2. 5 gallons molasses on each ridge.
3. 5 gallons molasses in each furrow.
4. No molasses.

In addition, each test received the usual amounts of sulphate of ammonia or bean cake. The molasses was applied immediately after digging the furrow in order to "lose its harmful action on the young cane." The amounts of molasses applied were not, however, the same in all the experiments,† nor the amounts of nitrogenous dressings, but were identical in all the tests in each individual locality. The results have been collected in the following table, on the basis of 2 acres to a "bouw," 133 pounds to a "picul," 1 1-3 pounds to a "katti," and 5 gallons to a "kerosene-tin," and stated in short tons per acre.

***See note page 8.**

†The molasses applications varied from 23,000 to 46,000 pounds per acre, sulphate of ammonia from 66 to 330 pounds per acre, and bean cake from 66 to 166 pounds per acre. The molasses was about 64 Brix.

	Molasses on Ridge and in Furrow.		Molasses on Ridge.		Molasses in Furrow.		No. Molasses.	
	Cane.	Sugar.	Cane.	Sugar.	Cane.	Sugar.	Cane.	Sugar.
1	.....	....	31.52	4.09	.....	....	29.73	3.83
2	53.86	5.05	53.00	5.21	51.56	5.05	52.93	5.21
3	64.48	6.20	59.40	5.68	57.26	5.02	51.68	4.49
4	59.40	4.39	55.44	4.85	57.55	5.28	50.56	4.65
5	64.28	6.53	59.70	6.01	62.96	6.47	58.81	6.01
6	42.80	5.05	43.07	5.21	49.24	6.04	42.80	4.92
Avg.	56.96	5.44	50.36	5.18	55.71	5.57	47.75	4.85

While the general average shows a distinct gain in cane and sugar, due to molasses, there are not wanting specific instances where molasses produced the contrary of good results· Better results were obtained when the molasses was placed in the furrow and worked into the soil, about six weeks previous to the planting, than when poured onto the ridges. The tests in the first series, with molasses both in the furrow and on the ridges, received twice as much of that material as those in the second and third series, but show in the average but a slight increase in the weight of cane and a loss in sugar when compared with the third series. The larger applications of molasses had a tendency to make the cane lodge, reducing the sucrose content of the cane and causing more dead canes than with the lighter applications.

The general conclusions of the author are as follows:—

"A fertilization with molasses can be recommended on the light soils of Java. For heavy soils, further trials are necessary.

"There are several possibilities as to the cause of the favorable action of molasses. To soils not very rich in potash, this element will be supplied. The organic matter of the molasses may hasten the growth of the cane. This organic matter cannot, however, be placed on a par with that resulting from the decay of vegetable matter; it is almost exclusively in the form of sugars, which ferment and disappear very quickly in the soil, without leaving anything behind which can be compared with humus. It may be that the decomposition products of the molasses exert a solvent action on the soil elements, making a greater amount of nutrients available to the plant. This possibility is based on the opinion of many planters that a molasses treatment makes the subsoil more friable and more easily worked. Or, finally, the nitrogen in the molasses (about 0.2 to 0.3 per cent.) has a valuable influence, but not sufficient to account entirely for the increase in crop. It is possible that all these influences are working together to produce a favorable result.

"The molasses in the natural fluid state is not conveniently handled. Mixing with press cake, furnace ashes, etc., helps but little, since these materials absorb too small an amount; while bagasse, which would absorb considerable quantities, is but seldom available in sufficient quantities. It is still a question to be decided whether it will pay to evaporate the molasses to dryness and grind up the product so obtained."

Aside from the above experiments, we have not found any further reference in the literature at our disposal to the effect of molasses as a fertilizer for cane. In the sole instance where molasses was applied to the growing cane, disastrous consequences followed. It is not an unusual custom in these Islands, where the mill is conveniently situated, to run the waste molasses into ditches from which it is carried in the water intended for irrigating fields lying below the mill. It is pertinent to inquire if the effects of such applications of molasses to fields under cane and receiving liberal additions of nitrogenous fertilizer would result to the same advantage of the cane crop as where molasses is distributed on fields lying fallow or where a considerable interval of time elapses between the molasses application and the planting of the seed cane.

The soil is a complex of many micro-organisms, different races of which are variously influenced by any amendment which may be made to the character of the soil. Four predominating transformations of the nitrogenous bodies in the soil are constantly occurring, ammonification, nitrification, nitrogen fixation, and denitrification. The first three, from an agricultural standpoint, may be termed constructive, the last is destructive. All are due to definite organisms, a large number of which have been isolated and described, and their nature studied in pure culture. It has been found that the presence of carbohydrates exerts a distinct influence on their respective actions. Lipman [9] found that dextrose depressed ammonification of peptone very considerably. Later experiments by the same author and Brown [10] confirmed their previous observations. Ammonification of the nitrogen from cotton-seed meal was affected similarly, but the effect on nitrogen supplied as blood was not so marked.

The process of converting the ammonia nitrogen into nitrate nitrogen is considerably affected by the presence of carbohydrates. In the early eras of nitrification tests, it was usually accepted. following the results of Winogradsy and Omelianski,[11] that soluble organic matter inhibited nitrification. Later researches have demonstrated that nitrification can proceed vigorously in the soil in the presence of large quantities of such organic matter as that of peptone, cottonseed meal, or cow manure.[12] But whether the continued application of the more easily decomposable carbohydrates would have a similar effect has not received the same amount of attention.

In 1907, A. Koch reported results of experiments where the influence of the addition of sugars to the soils was studied.[13] He observed harmful effects of sugar on cultivated plants, but beneficial effects when the application of the sugar preceded the sowing of the seed by about four months. The activity of the nitrogen fixing organisms was stimulated, amounting to a fixation of about 8 or 10 milligrams of nitrogen per gram of sugar. A single application of the sugar produced the best results, but large quantities seemed to injure the activity of the organisms. It was found that molasses caused a diminution of the nitrogen in the soil.

EXPERIMENTAL WORK.

For the purpose of studying the effects of carbohydrates on the various transformations of nitrogenous fertilizers, soil samples from three different parts of a plantation growing cane under irrigation were procured. The condition of the fields at the time of taking the samples was as follows:

1. Young plant cane standing about two feet high. This field had just received a dressing of sulphate of ammonia. The sample was taken from the top of the furrow, avoiding as far as possible any contamination by the applied fertilizer.

2. Soil taken from the outside edge of a field of mature cane, from the bottom of a furrow.

3. Soil taken in the middle of a field of mature cane, from the bottom of a furrow. The soil was naturally heavily shaded by the growing cane and not as freely exposed to the air as with number 2.

The analyses of these soils were as follows:

AGRICULTURAL ANALYSIS.

	1	2	3
Volatile matter	12.30	13.02	11.29
Insoluble residue	14.28	27.00	26.42
Soluble silica	26.22	14.26	15.28
Potash	.30	.18	.22
Soda	.49	.34	.29
Lime	.54	.41	.44
Magnesia	.72	.60	.70
Ferric oxide	18.21	22.50	21.46
Aluminic oxide	26.44	20.90	22.89
Phosphoric acid	.38	.37	.38
Sulphuric acid	.18	.08	.11
Chlorine	.01	.01	.01
Nitrogen	.09	.06	.044

MECHANICAL ANALYSIS.

	1	2	3
Loss on ignition	21.06	18.82	18.01
Coarse grits	.15	2.06	.42
Fine grits	.62	.42	.75
Coarse sand	.48	.78	.52
Medium sand	1.12	1.82	1.31
Fine sand	12.16	12.26	11.02
Coarse silt	18.43	19.65	22.65
Fine silt*	34.77	28.55	29.11
Clay†	11.21	16.64	16.21
True clay‡	1.86	3.08	3.20

SOLUBLE IN WATER.

Parts per 100,000, or milligrams per 100 grams dry soil.

	1	2	3
Lime	3.752	4.802	2.702
Potash	2.952	4.290	3.169
Phosphoric acid	1.457	1.210	1.120
Sodium bicarbonate ..	8.580	15.470	12.220
Sodium chloride	13.750	20.950	8.000
Total mineral matter..	53.750	50.230	34.980
Nitrogen, ammonia ..	5.17	3.90	4.64
Nitrogen, nitrite	.024	.024	.024
Nitrogen, nitrate	4.00	.300	.260

***By difference.**
†Sedimented 24 hours.
‡Sedimented 7 days.

The earliest method of soil bacteriological examination rested on the number of organisms in a given weight of soil. Immediately on receipt at this laboratory, the three soils were tested for their bacterial count. The results in number of organisms per gram of dry soil growing in four days on the dextrose-peptone-agar medium described by Lipman were:—

Soil 1	36,000,000
Soil 2	12,000,000
Soil 3	18,000,000

The addition of dextrose to a soil has been shown by Lipman[10] to produce an enormous increase in the number of bacteria growing on dextrose-peptone-agar, but this increase bore no relation to the ammonification power of the soils as measured in peptone solution or in the soils themselves; nitrification, however, was markedly checked in the soils receiving dextrose.

Two methods of observing the action of the ammonifying, nitrifying, and denitrifying organisms are possible; one by inoculating with a definite amount of soil into solutions containing the nitrogen in a definite form and mineral nutrients, or by supplying the nitrogen combination to the soil itself supplied with the necessary moisture content. The former does not reflect field conditions, and in the hands of many investigators has failed to give results corresponding to actual field tests. In the experiments which follow, both methods were used; it will be noticed that in the solution series the influence of the added sugars was far more distinct than in the soil series, yet the general order of results, with but few exceptions, is the same in both instances. In the solution tests, 100 cc. of the solution were inoculated with the equivalent of 10 grams of dry soil; in the soil tests, the equivalent of 200 grams of dry soil was placed in a beaker with a stirring rod, water added to produce two-thirds saturation, the necessary nitrogen compound and sugars added, and the beaker covered with filter paper securely fastened with a rubber band. The beaker and contents were weighed and when the experiment extended over several weeks, the beaker was re-weighed each week, and the water lost by evaporation replaced. Two-thirds saturation was adopted as the optimum moisture content. This was the average saturation of the soil in a series of field experiments concluded at this Station in 1903[14] for the months of February, March, and April, or the same time of the year at which the investigations recorded here were carried on, where the cane received three inches of water per week and produced the largest yields. The tests were conducted in beakers instead of Erlenmeyer flasks, since in the latter, unless a very large container is used, there is not much of the surface of the soil exposed to the air, a condition essential for good bacterial action. The incubation was carried on in a hole sunk in the ground to a depth of six feet and securely boarded in. The cultures were therefore always in the dark and at an equable temperature approaching that of the surrounding soil. The temperature variations were never greater than one degree centrigrade between day and night, and varied from a minimum of 21° C in February to a maximum of 24° C. in April. One series in each experiment received an addition of 0.5 gram dextrose to each 100 cc. of solution or 200 grams of soil; a second series received 0.2 gram molasses to the same quantities of solution or soil. The composition of this molasses was: sucrose, 42 per cent; invert sugar, 11.9 per cent; potash, 5.3 per cent; nitrogen, 0.26 per cent. A third series received no addition of carbohydrate, and served as a check.

TEST 1.

Ammonification in Solution.

Ammonification is the first process in the transformation of organic forms of nitrogen into a form available to the growing crop. It implies the change of the nitrogen of such materials as blood, hoofmeal, tankage, fishcrap, and also the humus nitrogen of the soil, to a condition whence it may be further changed into the form of nitric nitrogen. The material used in this test was peptone, a mixture of cleavage products obtained from proteids, and selected because of its ready solubility in water and not being coagulated when subjected to the temperature necessary for sterilization. A one per cent solution was used, 100 cc. being placed in cotton-plugged Erlenmeyer flasks and sterilized in an autoclave. After seeding with 10 grams of soil, the cultures were placed in the underground cupboard and incubated six days.

The results of this test are:—

Ammonia Nitrogen, Milligrams per 100 cc.

	Nothing.	0.2 Molasses.	0.5 Dextrose
Soil 1	105.56	93.52	31.08
Soil 2	102.76	96.32	38.64
Soil 3	90.02	77.42	28.00
Average	99.45	89.09	32.57

TEST II.

Ammonification in Soil.

To 200 grams dry soil, two-thirds saturated, 100 milligrams of nitrogen as peptone were added and thoroughly admixed, dextrose and molasses added to two lots, and allowed to stand 22 days. In the soil, the competing action of the various organisms does not allow such definite results as in the solution; and it is necessary, in order to understand somewhat of the transformations occurring, to take into account in addition to ammonia nitrogen, the nitric nitrogen formed by the action of the nitrifying organisms on the ammonia previously elaborated by the ammonifiers.

Nitrogen, Milligrams.

	Ammonia.			Nitric.			Ammonia & Nitric.		
	Nothing.	Molasses.	Dextrose.	Nothing.	Molasses.	Dextrose.	Nothing.	Molasses.	Dextrose.
Soil 1...	2.37	.....	1.51	66.43	63.50	60.48	68.80	63.50	61.99
Soil 2...	3.02	1.51	4.54	64.98	59.73	54.43	68.00	61.24	58.97
Soil 3...	15.10	19.39	14.36	37.06	26.33	31.00	52.16	46.12	45.36
Average	6.83	6.97	6.80	56.16	49.85	48.64	62.99	56.95	55.44

The effect of the added carbohydrates on the ammonification of peptone in solution is very evident, a half gram of dextrose reducing the action two-thirds; and molasses, representing about a tenth of a gram sucrose and invert sugar, producing an approximately proportional effect. In the soil, the differences are not so marked, but the general order is about the same; there is in the combined ammonia and nitric nitrogen content a regular drop accompanying the increased carbohydrate content. This table illustrates the need, as has already been mentioned, of determining both the nitrate and ammonia nitrogen in the soils, more especially when the duration of the experiment is more than a very few days.

Denitrification.

The reduction of nitrates by the action of bacteria in sewage was first observed by Dr. Augus Smith in 1867. [15] Previous to this, in 1862, Göppelsröder [1] reported a reduction of nitrates in the soil. This fact was confirmed later by Schloesing, who also found that soil when heated to 100° lost this faculty. The definite knowledge of the actions of the denitrifying bacteria dates from the publication of the results of Gayon and Dupetit in 1882.[4] They succeeded in isolating two organisms which were able to reduce nitrates with the evolution of free nitrogen, and others which could reduce nitrates to nitrites. Jensen[16] showed that certain races of denitrifying organisms would grow under aerobic conditions, and that in the absence of carbon compounds, no denitrification takes place.

TEST III.

Denitrification in Solution.

The bacteria effecting the reduction of nitric nitrogen may cause an actual loss of nitrogen by converting the nitrate nitrogen into gaseous nitrogen or nitrogen compounds; or an apparent loss by changing the nitrate nitrogen into ammonia, nitrite, amido, or insoluble albumenoid forms. Whilst the first is the most serious of these phenomena, the others are none the less of much importtance, inasmuch as they withdraw from the nutrition of the plant nitrogen which may have been applied with the intention of immediate availability.. The action of these organisms depends largely on the presence of sufficient organic matter to supply them with energy. The straw of fresh manure will furnish such a supply, this explaining the fact that frequently when applied alone, and usually when applied along with nitrate of soda, fresh manure has a deleterious action on crop growth. Carbohydrates, such as the sugars and starch, work in this direction more energetically, and the injurious effect is still more pronounced in poorly drained and wet soils. One of the products of the denitrifying action of these organisms working on nitrates of soda or potash in the presence of a carbohydrate, is the bicarbonate or carbonate of the alkali. Various reactions have been suggested, three of which are given here; in the first two the carbohydrate source is citric acid or citrate of soda, in the third it is glucose.

$$5C_6H_8O_7 + 18NaNO_3 = 18N + 18NaHCO_3 + 11H_2O + 12CO_2.$$

$$5C_6H_5Na_3O_7 + 18NaNO_3 + H_2O = 18N + 27NaHCO_3 + 3Na_2 CO_3.$$

$$5C_6H_{12}O_6 + 24NaNO_3 = 24N + 24NaHCO_3 + 18H_2O + 6CO_2.$$

There would result, then, in addition to the loss of nitrogen, a production of alkaline carbonates or bicarbonates, which by deflocculating the soil particles would produce a poorly drained, clayey state of the soil, in which condition the beneficial nitrifying organisms are inhibited in their action and that of the denitrifying bacteria further encouraged. The solution in which this transformation is usually studied is that of Giltay, where the nitrogen is in the form of nitrate of potash and the carbohydrate element is supplied as citrate of soda. Preliminary experiments showed that when 10 grams of dry soil were added to 100 cc. of this solution, the nitrate was entirely destroyed in three days. The following results are from analyses made two days after inoculation. The original solution contained 28.84 milligrams nitric nitrogen per 100 cc.

Milligrams Nitric Nitrogen per 100 cc.

	Nothing.	Molasses.	Dextrose.
Soil 1	19.60	13.44	10.36
Soil 2	19.97	15.50	14.67
Soil 3	20.36	16.24	14.56
Average	19.98	15.06	13.20

These tests show that by increasing the amount of carbohydrate in the solution, an accelerated action resulted. Another series was started in which the citrate of soda of the Giltay solution was replaced by dextrose, sucrose, and molasses, in correct amounts to make the carbon content of the solutions identical with that of the Giltay. Two further tests were made, one with a solution without carbohydrates, but with the mineral nutrients as given in Giltay's formula, and one with a strong soil extract to which nitrate of soda was added, but no minerals or carbohydrate. All solutions were, after proper sterilization, inoculated with the equivalent of 10 grams of dry soil, number 3.

Milligrams per 100 cc.

Time Days.	Carbohydrate.	Nitrate Nitrogen Original.	Nitrate Nitrogen Found.	Ammonia Nitrogen Found.
21	0	28.74	28.34	0
21	Dextrose	"	0	4.76
21	Sucrose	"	0	5.18
21	Molasses	"	0	5.60
5	Dextrose	"	0	4.3
5	Sucrose	"	0	3.9
5	Molasses	"	0	5.1

The soil extract was supplied with nitrogen as nitrate of soda to the extent of 46.76 milligrams per 100 cc.; whilst the soil extract itself contained 5.6 milligrams of ammonia nitrogen in 100 cc., or a total of 52.36 milligrams. After ten days the solution contained 51.52 milligrams of nitric nitrogen per 100 cc. and a trace of ammonia.

These results show that in the absence of carbohydrates the denitrifying organisms do not functionate; that the organic matter dissolved from this soil by water cannot supply the necessary energy; and that in the presence of dextrose, sucrose, or both as combined in molasses, sufficient energy is provided to entirely destroy the last trace of nitrate in five days.

TEST IV.

Denitrification in Soil.

To 200 grams of dry soil, 117 milligrams of nitrogen in the form of sodium nitrate were added, with water sufficient for two-thirds saturation and the usual amounts of dextrose and molasses. After six days, analysis gave the following results:

Milligrams, Nitrogen.

	Nitric.			Ammonia.			Nitric & Ammonia.		
	Nothing.	Molasses.	Dextrose.	Nothing.	Molasses.	Dextrose.	Nothing.	Molasses.	Dextrose.
Soil 1...	113.9	111.7	99.6	1.5	0	4.5	115.4	111.7	104.1
Soil 2...	108.0	96.6	74.8	.7	0	.7	108.7	96.6	75.5
Soil 3...	99.6	95.8	86.8	.8	0.8	3.0	100.4	96.6	89.8
Average	107.2	101.4	87.1	1.0	0.3	2.7	108.2	101.6	89.8

The alkalinity of these soils calculated to parts of bicarbonate of soda per 100,000 of soil was:—

	Nothing.	Molasses.	Dextrose.
Soil 1	31.7	44.9	54.3
Soil 2	27.1	44.9	58.9
Soil 3	27.1	36.2	44.9

The loss of nitrogen and amount of alkalinity increased regularly with the greater amount of carbohydrate present; but the difference, while definite, were not very great. Thinking that a greater interval of time would produce a more pronounced effect, soil 2 was treated in a manner similar to the above, but allowed to stand 48 days, the water lost by evaporation being replaced at weekly intervals, with the following results.

Milligrams, Nitrogen.

	Nitric.	Ammonia.	Nitric and Ammonia.
Nothing	98.28	3.02	101.30
Molasses	92.17	3.02	95.25
Dextrose	90.72	3.02	93.74

It was evident that the time factor had no decided influence. A third series was accordingly started, the soils being allowed to stand four weeks, at the end of each weekly period replacing the water lost by evaporation and also in the molasses and dextrose lots, supplying these elements anew in amounts equal to that first applied, viz., .2 and .5 gram respectively. The nitrogen added as nitrate amounted to 48.5 milligrams.

	Nitric.			Ammonia.			Nitric & Ammonia.		
	Nothing.	Molasses.	Dextrose.	Nothing.	Molasses.	Dextrose.	Nothing.	Molasses.	Dextrose.
Soil 1...	57.29	35.15	2.92	1.56	.78	1.56	58.85	35.93	4.48
Soil 2...	50.51	16.55	2.92	1.56	1.56	1.56	52.07	18.11	4.48
Soil 3...	49.80	16.57	2.92	1.56	.78	1.56	51.36	17.35	4.48
Average	52.53	22.76	2.92	1.56	1.04	1.56	54.09	23.80	4.48

It will be noticed that in the nothing series there was more nitric nitrogen present at the end of the experiment than was supplied as nitrate of soda. This is undoubtedly due to the ammonification and subsequent nitrification of the organic matter in the soil produced by favorable moisture and temperature conditions during the time of the experiment; where dextrose was added a profound effect resulted. Of 48.5 parts of nitrogen supplied as nitrate, only 2.92 parts remain as such, equivalent to a disappearance of 94 per cent. A small part of this nitrogen is retained in the form of ammonia compound, and an unknown amount in the form of insoluble albumenoid form. With molasses, containing only about a fifth as much carbohydrate, the disappearance of nitrate nitrogen was much less, but equally distinct, the average loss of the three soils being 53 per cent. This, as with the dextrose, does not represent a total loss of nitrogen, but it shows the quantity of immediately available nitrogen removed from the growing crop. It represents, to a considerably exaggerated extent, what conditions are obtaining in an irrigated plantation where dressings of nitrate of soda are applied, perhaps in the irrigation waters, and the waste molasses allowed to run at intervals into the water supply to these fields.

The theory of denitrification according to Stoklasa and Vitek [17] is that "one class of organisms, the *ammonifiers,* liberate free hydrogen from the organic nutrient, and reduce nitrate to nitrite. This is then reduced to ammonia by the alcohol which is produced in the anaerobic fermentation process, according to the formula

$$C_2H_5OH + N_2O_3 = 2CO_2 + 2NH_3.$$

"The *denitrifiers* act much more intensely upon the reduced nitrate solution, the theory being that the alcohol reduces twice as much nitrite as in ammonification, with the evolution of free nitrogen, thus:

$$C_2H_5OH + 2N_2O_3 = 2CO_2 + 4N + 3H_2O.$$

"The authors show from their experiments that the pentose-carbo-hydrates, xylan, and araban are very poor sources of energy for denitrification processes, but favor that of ammonification; and since these pentosans are exceedingly prevalent in soils and stable manure, they conclude that natural conditions in fields fertilized with nitrates favor ammonification rather than denitrification." When the carbohydrate supplied is one capable of ready fermentation into alcohol, like sucrose and glucose, it can be readily seen that this theory would explain an actual denitrification process, or loss of nitrogen, rather than a conversion into ammonia, a loss which would be intensified by frequent applications of the sugars to the soil.

A series of tests was carried on in Giltay solutions in order to determine the amount of nitrogen which had actually disappeared. Several flasks containing 100 cc. of solution were inoculated with equal amounts of a suspension of soil 3 in water. The amount of nitrogen thus introduced was extremely small and not allowed for. After three days, the solutions gave no test for nitrates with diphenylamine. The entire contents of one series of the flasks were digested according to the Kjeldahl method and the total nitrogen determined; a duplicate series was distilled with calcined magnesia for ammonia nitrogen and gave quantities varying from a trace to 1.5 milligrams of nitrogen as ammonia per 100 cc. These quantities, being so small, are included in the nitrogen figures in the following table. The tests were started on May 19.

Date.	Nitrogen present, Milligrams per 100 cc.	Average.	Nitrogen lost, Milligrams per 100 cc.	Per cent. of Nitrogen Lost.
May 19	29.26	....	....	....
" 19	29.26	29.26	....	....
" 23	9.38			
" 23	9.10	9.24	20.02	68.4
" 25	9.10			
" 25	8.40	8.75	20.51	70.1
" 27	8.96			
" 27	11.20	10.08	19.18	65.5
" 31	8.54			
" 31	9.38	8.96	20.30	69.4
June 4	9.24			
" 4	9.10	9.17	20.09	68.7

In solution with citrate of soda as the source of energy, the denitrifying organisms cause the disappearance of all the nitrate nitrogen and an actual loss of 68 per cent of the total nitrogen present. The balance is left mainly as albumenoid nitrogen.

According to Ampola and de Grazia [24] lime nitrate offers more resistance to denitrifying bacteria than sodium nitrate. This point was studied in a series of three experiments with soil number one, to two of which the usual quantities of dextrose and molasses were added. The 200 grams of dry soil were given 115.5 milligrams of nitrogen as calcium nitrate, two-thirds saturated with water, and allowed to stand two weeks, with the following results:

Milligrams Nitrogen.

	Nitric.	Ammonia.	Nitric and Ammonia.
Nothing	114.91	0	114.91
0.5 Molasses	108.87	1.51	110.38
0.5 Dextrose	86.19	1.51	87.70

In the absence of added carbohydrates, there was no loss of nitrogen from this material. Molasses and dextrose induced denitrification in the same order as in the tests with nitrate of sodium.

TEST V.

Nitrification in Solution.

Whilst aeration is thoroughly understood to be essential as regards nitrification in soils, and for this reason nitrification in solution cannot represent successful field conditions, nevertheless, for the purpose of this investigation, valuable results from such tests might be expected. The solution used was that of Omeliansky containing mineral nutrients and 41.9 milligrams of nitrogen as ammonium sulphate; to these solutions, sterilized as those with peptone, about half a gram of sterilized calcium carbonate in suspension was added, to provide the conditions necessary for favorable nitrification. The time of the test was 28 days; 10 grams of soil as usual were employed for inoculation.

Milligrams, Nitrogen.

	Nitric.			Ammonia.			Nitric & Ammonia.		
	Nothing.	Molasses.	Dextrose.	Nothing.	Molasses.	Dextrose.	Nothing.	Molasses.	Dextrose.
Soil 1...	6.16	3.36	.98	29.12	26.32	24.64	35.28	29.68	25.62
Soil 2...	7.42	2.94	.84	27.16	25.90	23.80	34.58	28.84	24.64
Soil 3...	2.66	2.24	.56	30.38	27.44	25.48	33.04	29.68	26.04
Average	5.41	2.85	.79	28.89	26.55	24.64	34.30	29.40	25.43

The influence of carbohydrates on the process of nitrification in solution is very evident, the extent of loss increasing with the amount present. A further action is apparent in the actual loss of nitrogen, shown by the quantities of nitric and ammonia nitrogen left. This is most probably largely caused by the increased activity of the denitrifying organisms introduced with the soil inoculum, due to the presence of the carbohydrates, whereby some of the nitrate formed by the nitrifying organisms is changed to free nitrogen or degraded into insoluble forms. This last property is possessed not only by bacteria, but the moulds and yeasts, which are omnipresent in soils, also withdraw large quantities of nitrogen present as ammonia and convert it into insoluble albumenoid compounds. Rothe [18] has shown that when seeded into solutions containing ammonium sulphate, lime carbonate, dextrose, and nutrients, the common moulds, *Penicillium glaucum* and *Aspergillus glaucus*, can convert from 17 to 24 per cent of the nitrogen into albumenoid form, of which about one-quarter is soluble in water.

TEST VI.

Nitrification in Soil.

Soils with and without molasses and dextrose, two-thirds saturated and supplied with 192 milligrams of nitrogen as ammonium sulphate, gave after four weeks the following results:—

Milligrams, Nitrogen.

	Nitric.			Ammonia.			Nitric & Ammonia.		
	Nothing.	Molasses.	Dextrose.	Nothing.	Molasses.	Dextrose	Nothing.	Molasses.	Dextrose.
Soil 1...	67.29	44.60	77.11	80.89	83.92	68.04	148.18	128.52	145.15
Soil 2...	90.00	83.16	87.69	59.70	52.92	34.78	149.70	136.08	122.47
Soil 3...	21.17	26.46	33.26	101.30	98.28	90.72	122.47	124.74	123.98
Average	59.49	51.41	66.02	80.63	78.37	64.51	140.12	129.78	130.53

These results in no wise compared with the solution tests, and lead to no definite conclusions. The differences as regards nitrification were apparently in favor of the tests receiving dextrose, whilst molasses had a contrary action. These tests were accordingly repeated, the water being replaced as before at weekly periods, and new additions of molasses and dextrose given at the same time; 100.6 grams of nitrogen as ammonium sulphate were added to each soil at the beginning.

Milligrams, Nitrogen.

	Nitric.			Ammonia.			Nitric & Ammonia.		
	Nothing.	Molasses.	Dextrose.	Nothing.	Molasses.	Dextrose.	Nothing.	Molasses.	Dextrose.
Soil 1...	35.46	11.32	21.19	40.75	39.24	22.63	76.21	50.56	43.82
Soil 2...	61.76	47.54	9.76	9.07	3.02	1.56	70.83	50.56	11.32
Soil 3...	31.70	22.62	14.34	39.99	31.70	23.39	71.69	54.32	37.73
Average	42.97	27.16	15.10	29.94	24.65	15.86	72.91	51.81	30.96

As with the tests for denitrifying action, these experiments with repeated additions of the carbohydrate show very decided differences. Also, as with the other tests, they show the reactions possible in a field where ammonium sulphate has been applied, either in mixed fertilizer or as special dressing, and the land irrigated at the usual intervals with water into which the waste molasses is allowed to run. In these tests, where 42.7 per cent of the nitrogen added as ammonium sulphate was found as nitrate, and 72.4 per cent as ammonia and nitric nitrogen, the addition of molasses reduced the recovery to 26.4 and 51.4 per cent respectively. Not only was there less immediately available nitrogen present, but there was an actual apparent loss. This loss is called apparent, as part of that not accounted for is in the form of insoluble albumenoid compounds; and on the cessation of addition of molasses to the irrigation water and disappearance of the sugars already supplied, the ammonifying and nitrifying organisms will function normally and restore this nitrogen to an available form; always providing, however, that the excessive alkalinity produced by the denitrifying organisms has not placed the soil in such a bad condition that, in the absence of sufficient aeration, the beneficial organisms cannot thrive vigorously. Such a final state of affairs could be corrected only, after the removal of the crop, by tillage and drainage, or previously by the addition of suitable soil amendments.

TEST VII.

Nitrogen Fixation.

This test was carried out only in solution. Ten grams of soil were placed in glass flasks containing 200 cc. of a 1 1-2 per cent. of mannite and suitable amounts of mineral nutrients, exclusive of nitrogen. In other words, no nitrogen was present in these solutions save that contained in the 10 grams of soil used for inoculation, which was determined and deducted from the final results. After standing 10 and 12 days, the total contents of the flasks were analyzed for nitrogen, with results as follows:

Milligrams Nitrogen in 200 cc.

	Soil 1	Soil 2	Soil 3
10 Days	29.12	36.82	36.82
12 Days	32.76	43.40	40.32
Average	30.94	40.11	38.57
Nitrogen in soil	7.42	5.18	3.64
Nitrogen fixed	23.52	34.93	34.93
Nitrogen fixed p. gram mannite	7.8	11.6	11.6

The flasks containing these tests offered a large surface to the air; in every case there was developed the brown film characteristic of the *Azotobacter chroococcum* of Beijerinck; plate cultures on mannite agar gave the same colonies as are described for this organism.

These results show a possible benefit to be derived from the application of molasses to such soils as were used in these experiments. Such beneficial results would be acquired, however, only when the molasses is applied to fallow land, or at least to the soil some time previous to the planting of the cane. In such cases there could be expected an increased nitrogen content of the soil, manufactured into albumenoid form from the nitrogen of the air by these nitrogen-fixing bacteria, a form easily ammonified and nitrified by the proper organisms subsequently. It has been found that these nitrogen-fixing species do not function well, or not all, in the presence of a sufficient supply of available nitrogen. They then prefer to use the food already prepared for them, rather than elaborate their own supply. It is only when deprived of such a source of nourishment, and in the presence of a proper supply of organic matter to furnish them with the necessary energy, that they look to the abundant nitrogen of the air and fix it in the soil during their development. It is therefore easy to see that when molasses is placed on lands to which artificial nitrogenous dressings are supplied, this one beneficial property of the sugars in the molasses will be nullified.

The results of these experiments should be accepted with some reservations. All the conditions are exaggerated considerably over those which exist under cultural conditions in the cane fields. Nevertheless, a greater or less part of these changes must take place when molasses are applied to growing crops. It is of course unfortunate that the large amounts of valuable potash and nitrogen combinations contained in the molasses cannot be utilized in the convenient and economical manner of discharging it into the irrigation water. The potash, however, can be largely preserved when the molasses is burned, and the results of trials in this direction will be found in the report of the committee on the utilization of waste products presented at the annual meeting of the Hawaiian Sugar Planters' Association of 1909.

Two conclusions only can be reached from the results of the above experiments:—

1. Molasses applied at intervals on land on which cane is growing and fertilizer has been applied will work harm by destroying nitrates already applied or by preventing the formation of nitrates from other sources of nitrogen supplied in the fertilizer.

2. Molasses applied to land lying fallow or at an interval of several weeks prior to the planting of the crop may produce beneficial results by providing a stimulus to the nitrogen-fixing bacteria of the soil and thereby adding a store of nitrogen to the soil in a form which can be made readily available to the crop at a later date by the other organisms in the soil.

Action of Bacteria in Soil from Different Depths.

The number of the soil organisms diminishes constantly but irregularly as the samples are taken to greater depths. This will depend greatly on the character of the soil, whether open and well-drained, or compact and poorly-drained. Chester [19] found that the bacteria occur in maximum numbers within the first six inches of the surface, reaching up to 1,900,000 per gram of dry soil, and undergoing rapid diminution to 4,000 at a depth of two feet. King [20] found a drop from 14,500,000 per cubic centimeter of soil at two inches to 2,500,000 at a depth of 12 inches in a soil which was not disturbed, but when stirred to a depth of ten inches, the variation was from 7,300,000 to 5,300,000. Where drainage is good, and water is supplied at regular intervals of irrigation, there would be a tendency for the bacteria to be carried downward to a considerable depth. The conditions of aeration, moisture content, and temperature being manifestly different in the lower zones than near the surface, there would be an alteration in the bacterial flora thus brought down, the aerobic suffering more or less partial extermination, and the anaerobic correspondingly receiving an impetus to multiplication.

Four soil samples were taken at increasing depths of one foot each, and the organisms counted in the respective samples after air-drying, with results as follows:—

Depth.	Number of Organisms per Gram Dry Soil.
1st foot	8,000,000
2d "	5,000,000
3d "	5,000,000
4th "	1,000,000

The mechanical analyses were as follows:—

	1st foot.	2d foot.	3d foot.	4th foot.
Loss on ignition	19.56	20.11	20.39	22.75
Coarse grits	.12	.04	.00	.00
Fine grits	.12	.03	.00	.07
Coarse sand	.08	.06	.06	.07
Medium sand	.53	.21	.24	.25
Fine sand	7.81	8.30	7.30	5.66
Coarse silt	14.94	13.86	11.38	11.44
Fine silt*	40.72	41.95	45.05	40.28
Clay†	16.12	15.44	15.58	19.48
True clay‡	3.76	2.64	1.12	4.96

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*By difference.

†24 hours sedimentation.

‡7 days sedimentation.

The nitrogen contents of the soil, per cent. of dry soil, was .092, .065, .040, and .041 per cent, respectively.

Tests were carried out in solutions to compare the relative actions of the soils on different nitrogenous materials. Ten grams of dry soil were used as inoculum in all instances.

TEST VIII.

Ammonification in Peptone Solution by Soils from Different Depths.

Depth.	Time Days.	Ammonia Nitrogen Milligrams.	Time Days.	Ammonia Nitrogen Milligrams.	Average.
1st foot	6	93.24	7	102.48	97.86
2d "	6	95.20	7	92.96	94.08
3d "	6	83.58	7	90.72	87.15
4th "	6	76.02	7	90.36	83.19

The organisms transforming the organic nitrogen into ammonia are apparently present in considerable numbers down to a depth of four feet, but in decreasing numbers corresponding to the greater depths.

TEST IX.

Denitrification in Giltay Solution by Soils from Different Depths.

The solution at the start contained 23 milligrams of nitrogen from potassium nitrate per 100 cc. The results in milligrams of nitrogen per 100 cc. were:—

Depth.	Time Days.	Nitrogen Milligrams.	Time Days.	Nitrogen Milligrams.
1st foot	2	1.12*	3	1.54*
2d "	2	1.68*	3	1.12*
3d "	2	2.24	3	1.12*
4th "	2	21.84	3	.98*

*No nitrate nitrogen; figures represent ammonia nitrogen.

At the end of the second day, the two lower depths still gave a test for nitrate to diphenylamine sulphate, which disappeared after standing twenty-four hours more. The difference in rate of denitrification is due to the lesser number of organisms per unit weight in the two lower depths.

TEST X.

Nitrification in Omelianski Solution by Soils from Different Depths.

The solution contained 45.70 milligrams of nitrogen from ammonium sulphate in 100 cc. The time of incubation was 28 days.

Depth.	Milligrams of Nitrogen per 100 cc.		
	Nitric.	Ammonia.	Nitric and Ammonia.
1st foot	7.56	29.40	36.96
"	7.84	29.40	37.24
Average	7.70	29.40	37.10
2d foot	6.44	29.12	35.56
"	6.44	29.40	35.84
Average	6.44	29.26	35.70
3d foot	4.48	31.36	35.84
"	5.04	30.80	35.84
Average	4.76	31.08	35.84
4th foot	5.04	30.24	35.28
"	5.04	29.96	35.00
Average	5.04	30.10	35.14

Nitrification was most intense from the first foot of soil. The second foot produced a lesser amount of nitric nitrogen, and a further diminution is noticed in the two succeeding layers, which were practically the same.

TEST XI.

Nitrogen Fixation in Mannite Solution by Soils from Different Depths.

Two hundred cubic centimeters of solution were used in each case. The time of incubation was 21 and 22 days; 10 grams of air dry soil were used for inoculation.

Milligrams.

Depth.	Total Nitrogen.	Nitrogen in Soil.	Nitrogen Fixed.	Nitrogen Fixed per Gram of Mannite.
1st foot	47.32			
"	45.22			
Average	46.27	8.4	37.87	12.6
2d foot	45.96			
"	44.80			
Average	45.38	5.88	39.50	13.2
3d foot	41.58			
"	43.96			
Average	42.77	3.64	39.13	13.0
4th foot	42.44			
"	43.26			
Average	42.85	3.64	39.21	13.1

There was practically no difference between the soils in respect to their nitrogen-fixing powers. All the cultures showed the brown film characteristic of *Azotobacter chroococcum.* In the second foot, the film was much darker and the odor strongly putrefactive. With the exception of this depth, all solutions showed protozoa, both paramecium and amoeba, in great number; in the second foot the number was limited. The significance of these organisms will be referred to further on.

The Effect of Certain Fertilizing Elements of the Soil.

The soils used in the first series of experiment dried to a hard dense mass, similar in every respect to a clay soil. Soil No. 3 was treated with various substances, moistened with water, and allowed to stand a month, being stirred at intervals and the water lost by evaporation replaced. The additions made were as follows:—

No. 1—Nothing.
No. 2—0.5 gram gypsum to 500 grams soil.
No. 3—0.5 gram calcium carbonate to 500 grams soil.
No. 4—0.65 gram sodium nitrate to 200 grams soil.
No. 5—0.5 gram potassium sulphate to 500 grams soil.
No. 6—1 cc. carbon bisulphide to 500 grams soil.
No. 7—0.5 gram dextrose to 200 grams soil.
No. 8—1.0 gram molasses to 500 grams soil.
No. 9—0.5 gram double superphosphate to 500 grams soil.

At the end of the month, the soils were air dried, and their mechanical conditions noted. Soils 1 and 7 were heavy and sticky when wet, drying to hard, compact masses. The remainder of the soils were loose and granular when wet, and friable and easily pulverulent when dry. The amounts of material added were considerably exaggerated over that which obtains in agricultural practice. The differences in mechanical condition were very apparent even before the soils were dried out.

After being dried, the soils were analyzed for their moisture and nitrogen content, and a count made of the number of organisms in each.

Number.	**Organisms per Grams Dry Soil.**	**Total Nitrogen, Milligrams per 100 Grams of Dry Soil.**
1	7,000,000	56.0
2	4,000,000	54.8
3	3,000,000	55.2
4	1,480,000	75.6
5	4,000,000	48.7
6	2,860,000	52.0
7	16,000,000	59.2
8	18,000,000	57.0
9	2,000,000	56.7

A drop in bacterial numbers from the one to which nothing was added is observed in all the soils with the exception of the two to which dextrose and molasses was supplied, where the number of organisms increased over two-fold. The soil originally contained 44 milligrams of nitrogen per 100 grams of dry soil, so that there has been an increase of this element in the soils in all cases with the exception of number 4. In this case there was added as nitrate 98 milligrams of nitrate nitrogen to 200 grams of soil, and there has been a disappearance of 17 milligrams of nitrogen together with a considerable diminution of the number of organisms. The non-fixation of nitrogen in the presence of nitrate agrees with results obtained by Lipman [21] in his studies of the *Azotobacter*, namely, that the presence of nitrates discourages the fixation of atmospheric nitrogen by those organisms.

Similar tests to those already reported were carried on with these soils in solution, 10 grams of dry soil being used for inoculation.

TEST XII.

Ammonification in Peptone Solution.

Number.	Milligrams Nitrogen as Ammonia in 100 cc.		
	6 days	7 days	Average
1	84.42	96.18	90.30
2	86.52	100.38	93.45
3	92.12	97.58	94.85
4	82.04	89.74	85.89
5	94.24	109.36	101.80
6	82.74	94.64	88.69
7	90.72	96.00	93.36
8	94.92	108.64	101.78
9	91.42	101.64	96.53

The addition of lime, as carbonate, sulphate, or phosphate, stimulated ammonification. Nitrate of soda and carbon bisulphide depressed the process. Dextrose had a slightly beneficial effect, but was considerably surpassed in this respect by molasses. The addition of this material and that of postassium sulphate produced equally favorable results. No relation can be discerned between the number of organisms and the degree of ammonification, confirming Lipman and Brown's results [10] referring to the effect of dextrose in increasing the absolute numbers of organisms in a soil, but not the relative ammonifying power.

TEST XIII.

Denitrification in Giltay Solution.

The original solution contained 29.3 milligrams nitric nitrogen per 100 cc. Results reported in milligrams nitric nitrogen per 100 cc.

Number.	Two Days.	Three Days.
1	8.22	1.49
2	24.64	1.32
3	24.08	1.49
4	19.04	1.87
5	16.94	1.94
6	26.13	13.16
7	14.36	1.12
8	12.32	1.68
9	22.76	3.17

The most efficient hindrance to denitrification was rendered by carbon bisulphide. It is very possible that the denitrifying organisms were those that were principally destroyed by the action of this compound, and that the considerable drop in numbers is partly explainable by the partial destruction of these particular organisms. This suggestion as to the action of carbon bisulphide is made tentatively, and would require further and more precise research before it could be offered as a definite conclusion. All additions to the soil seemed to check denitrification, the lime salts to the greatest, and the sugars to the least extent. The action of the sugars is apparently contradictory to the results reported in the molasses series: but it must be remembered that the sugars themselves had disappeared long before the end of the month during which the soils were standing. The increased number of organisms was not the denitrifying organisms, but most probably, as will be seen in Test XIV., the nitrogen fixing bacteria.

It has been suggested that volatile antiseptics placed in a soil play a role similar to that of sterilization; [23] many of the denitrifying species, being spore formers, are able to survive this treatment, and upon being restored to favorable conditions, resume their functions. The action of carbon bisulphide, however, has received other interpretations, and the result of this experiment and those that follow, would seem to indicate that the different organisms did not suffer destruction, but rather a readjustment of the numbers, and that the denitrifying organisms principally were checked in their development.

TEST XIV.

Nitrification in Omelianski Solution containing 45.7 milligrams of nitrogen from ammonium sulphate in 100 cc. Time, 28 and 29 days. Average of two determinations.

Number.	Nitric	Ammon. Nit.	Ammon. & Nitric.
1	4.76	35.84	40.60
2	4.48	36.40	40.88
3	5.88	35.28	41.16
4	9.06	35.56	44.62
5	5.04	35.56	40.60
6	5.32	35.56	40.88
7	4.76	35.28	40.04
8	5.04	34.72	39.76
9	4.20	36.12	40.32

The nitric nitrogen added in number 4 shows in the results in this table. Corrected for the amount added, there were approximately 5.04 milligrams formed. Lime carbonate had the most favorable action and superphosphate the least. This could be reasonably expected, since an alkaline soil or a soil treated with lime carbonate acts more favorably in respect to nitrification than an acid soil, where the process is checked. The fact that gypsum produced no increase in nitrate was surprising, since this material, in field practice, undoubtedly effects good results in this regard. According to Pichard, gypsum up to 0.5 per cent. accelerates nitrification more than any other substance known. [22] It is possible that the small quantity present in the inoculum in this experiment was not sufficient to produce a noticeable effect; or it may be that the beneficial results of gypsum applied to a soil is due to its mechanical and chemical action on the soil, producing conditions favorable for the action of the nitrifying bacteria, conditions which would not be duplicated under the arrangements of our experiments.

Another qualifying condition as regards the action of this material on nitrification is the nature of the soil treated. Similar results as regards the check to nitrification were obtained with soil from the field of the Experiment Station, [28] treated in lysimeters. In these experiments it was found that ground coral, applied at the rate of a ton to an acre, increased the nitric nitrogen recovered in drainage water by 1.35 pounds over untreated soil; gypsum effected a loss of 2.61 pounds, when applied in like proportions.

Carbon bisulphide stimulated nitrification to a slight extent. This result confirms our previous observation that this substance, in the quantity added (about 1 to 500), did not destroy the micro-organisms, but caused a re-proportioning of them. The nitrifiers are easily killed by heat; a subsequent experiment will show that an exposure of ten minutes to a temperature of 85° C. causes their death. Our results are similar, as regards this point, to those obtained by Lipman;[25] he found that carbon bisulphide caused an increase of nitric nitrogen of from 7 to 14 milligrams in 20 pounds of soil. Coleman [26] also found that while carbon bisulphide checks nitrification at first, it later exhibits a pronounced stimulating action on the nitrifiers.

TEST XV.

Nitrogen fixation in 200 cc. of 1.5 per cent. mannite solution. Time, three weeks.

Number.	Nitrogen Milligrams.		Average.	Nitrogen in Soil.	Nitrogen Fixed.
1	39.2	39.2	39.20	5.60	33.60
2	43.12	42.28	42.70	5.48	37.22
3	43.54	42.14	42.84	5.52	37.32
4	44.78	*	44.78	7.56	37.22
5	41.44	42.00	41.72	4.87	36.85
6	43.68	45.08	44.38	5.20	39.18
7	47.46	47.46	47.46	5.92	41.54
8	48.02	47.32	47.67	5.70	41.97
9	42.14	39.62	40.88	5.67	35.21

*Lost in distillation.

The soils to which the sugars had been added show the maximum power of fixing nitrogen. It is for this reason we have already pointed out the possibility that the increased numbers of organisms in these soils is to be largely attributed to increased *Azotobacter* organisms. The least improvement was effected by the acid superphosphate; and as acidity in the soil presents a check to *Azotobacter* development, this can be readily understood. The effect of carbon bisulphide, as with the other organisms, was not a destructive one. Maasen and Behn [27] found that while 1.7 parts of carbon bisulphide per 1000 in water destroyed *Azotobacter* in 24 hours, they survived in most soils for 48 hours. Lipman [25] found a slight gain as regards nitrogen fixation from soils treated with carbon bisulphide over those untreated. It is evident that in our experiments the *Azotobacter* were not destroyed by the application of the carbon bisulphide, and that later, under the favorable conditions of moisture and temperature, they exceeded in numbers those in the untreated soil.

The Effect of Pasteurizing Soil Suspension.

A quantity of Station soil was shaken for ten minutes with sterile water. Aliquot portions equivalent to 1 gram of soil were seeded into solutions of peptone, mannite, Giltay's nitrate solution, and Omelianski solution of ammonium sulphate. A portion was transferred to a sterile flask and heated for ten minutes at 85° C. After cooling, one gram equivalents were placed in solutions as with the unpasteurized suspension. The results of the ammonification test were:—

	Milligrams Nitrogen as Ammonia.	
	25 Days.	27 Days.
Pasteurized	99.96	103.32
Non-pasteurized	98.62	101.68

The denitrification test gave a reaction for nitrate with both the pasteurized and non-pasteurized inoculations after three days, which disappeared on the fifth day. A small amount of ammonia nitrogen remained in all the tests, amounting to from 0.92 to 1.26 milligrams of nitrogen. It was evident that the spore forming ammonifying and denitrifying organisms were not destroyed by the effect of pasteurization.

In the Omelianski solution, after 30 days, there were 4.2 and 4.8 milligrams of nitrate nitrogen in the solutions seeded with the non-pasteurized suspension, but neither at this time nor one month later did the tests seeded with the pasteurized suspension give a nitrate test. In the mannite solutions, the results were:—

	Nitrogen Fixed,	Milligrams
	27 Days.	32 Days.
Pasteurized	0.35	0.56
Non-pasteurized	32.13	29.96

Both the nitrifying and nitrogen-fixing bacteria succumbed to an exposure of ten minutes to a temperature of 85° C. Not being spore formers, they were entirely destroyed.

In all soils examined, there were present numbers of various forms of protozoa. According to Russel and Hutchinson, [23] the beneficial effects noticed after sterilization either by heat or volatile antiseptics may be largely or entirely attributed to the destruction of these larger forms of life. Their principal, if not sole food supply is derived from the living micro-organisms of the soil. At elevated temperatures they perish, but certain micro-organisms survive either by their resistance to the higher temperature or their property of forming heat-resistant spores, which on resumption of normal temperature return to or re-create the organisms from which they originated. These organisms are then free from the attacks of the larger organisms and are enabled to multiply more rapidly, and consequently functionate more strongly. The presence of these protozoa has been particularly noticeable in our work in the solutions of mannite inoculated with soil. The nonpasteurized inoculations showed them present, but in far fewer numbers than when soil was used for inoculation. In the pasteurized tests they were entirely absent. The effect of heat, then, has been to destroy the phagocytes, or large organisms, which prey on the living micro-organisms. Unfortunately, however, the beneficial organisms, such as the nitrogen-fixers, are almost entirely destroyed, and the nitrifiers entirely so. Sterilization is hardly an agricultural practice, but where it is used intentionally, such as when carbon bisulphide is applied for the purpose of correcting plant disease or insect attacks, or accidentally, where fires have occurred, or the soil exposed to the intense heat of the sun in the tropics, very excellent crop returns have been obtained. The theory of Russel and Hutchinson is in no wise antagonistic to these results. The phagocytes and beneficial parasites may be destroyed, but the dust in the air carried from adjoining and unaltered fields will speedily repopulate such lands with the beneficial smaller organisms. It has been found in laboratory work that extreme care was necessary in preventing the re-entrance of the widely disseminated nitrifying organisms into the sterilized soils; so that under field conditions, it can be readily imagined that re-inoculation of sterilized fields would quickly follow.

In addition to the work reported above, many of the organisms growing on agar have been studied under the microscope and their action in pure culture observed; but our data on these points present nothing peculiar or novel. The organisms can be generally identified with species already described and which are universally distributed in arable soils. Our work in this respect is incomplete, but will be resumed at a later date.

In conclusion, the writer desires to express his appreciation of the valuable assistance rendered him by W. J. Hartung, Assistant Chemist, both in the isolation, staining, and identification of various organisms, and in the analytical work involved in the preparation of this bulletin.

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AGRICULTURAL AND CHEMICAL SERIES

BULLETIN No. 35

REPORT OF WORK
OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

The Inversion of Cane Sugar Under the Influence of Acids and Neutral Salts.

BY NOEL DEERR.

HONOLULU, HAWAII
1910

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JAN 11 [illegible]

LETTER OF TRANSMITTAL.

To the Experiment Station Committee of the
Hawaiian Sugar Planters' Association,
Honolulu, Hawaii.

Dear Sirs:—I herewith submit for publication, as Bulletin No. 35 of the Agricultural and Chemical Series, an article by Mr. Noël Deerr, Sugar Technologist, entitled: "The Inversion of Cane Sugar Under the Influence of Acids and Neutral Salts."

Yours very truly,

C. F. ECKART,
Director.

Honolulu, Hawaii, September 28, 1910.

THE INVERSION OF CANE SUGAR UNDER THE INFLUENCE OF ACIDS AND NEUTRAL SALTS.

By Noël Deerr.

INTRODUCTION.

The inversion of cane sugar is a subject which has been of no inconsiderable importance in the development of certain theories in physical chemistry. It is one, then, on which a great amount of work has been done, and is, moreover, associated with the names of some of the most original thinkers of the older living generation. The work of Ostwald and Arrhenius and of other investigators has however been undertaken toward the development of the ionic hypothesis; and so far as the writer is aware, no detailed study of the inversion of cane sugar from the point of view of the cane sugar manufacturer has been made.

One very great point of difference which exists between the purely academic researches undertaken in the development of the theory of physical chemistry, and a study of inversion from the point of view of sugar manufacturer is that in the former the action of pure acids and salts are considered, and in cane juices and sugar house products generally a complex mixture of sugars, organic and inorganic salts exists. The bodies other than cane sugar, especially the salts, have a profound influence on the rate of inversion of cane sugar by acids, and it was with the view of elucidating certain points that have presented themselves to the writer, that the experiments described below were made.

Before giving in detail the results of the experiments made by the writer, it may be of use to collate the somewhat extensive studies already made on the inversion of cane sugar.*

A hypothesis most prominent since 1884 and due to Arrhenius[1] puts forward the conception that bodies, which are capable of conveying an electric current in aqueous solution, are split up in solution into their component parts, to which following Faraday, the name *ion* has been given. Thus hydrochloric acid in solution is considered as consisting of undissociated hydrochloric acid (HCl) and of hydrogen ions H and chlorine ions Cl. Similarly, sodium nitrate is considered as existing in solution partly as $NaNO_3$ and partly as Na and partly as NO_3. To the dissociated parts are supposed to be attached electric charges, positive in the case of the hydrogen and metals, and negative in the case of the acid ion—NO_3, Cl, SO_4, etc. The activity of acids in solution is on this hypothesis connected with the degree to which they become dissociated and this activity is again connected with the number of hydrogen ions present. Thus when it is said that hydrochloric acid is a stronger acid than acetic, under the ionic hypothesis, is meant that hydrochloric acid in solution splits up largely into H ions and Cl ions, and that acetic acid splits up into H ions and CH_3COO ions to a very much less extent, and that the difference in the strength of these acids is due solely and entirely to the different number of free hydrogen ions present. Hence it is considered by the supporters of the ionic hypothesis that the inversion of cane sugar under the influence of acids is due solely and entirely to the hydrogen ions.

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* I do this because in no textbook dealing with sugar manufacture is this subject more than briefly discussed.

RATE OF INVERSION OF CANE SUGAR BY ACIDS.—In 1867 two Norwegian chemists—Guldberg and Waage—developed what is known as the principle of active mass which is thus formulated—*"the rate of change in a chemical action is proportional to the active mass."** Thus if in any reaction there are two units present,

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* This law of mass action is one of the fundamental natural laws, equal in importance to Newton's laws of motion or to Mendel's principles of heredity. Though associated chiefly with the two chemists named, it had been less clearly conceived earlier by Berthollet, by Wilhelmy, by Harcourt, and by Esson, and later by Jellet and Van't Hoff in ignorance of the previous work of Guldberg and Waage. This law has several immediate applications to sugar manufacture. Thus an evaporator of 2000 square feet will evaporate twice the amount of water which one of 1000 square feet will, *other conditions being equal.* Here the active mass is the area of the heating surfaces. Let, however, the circulation in one evaporator be more efficient than in another of the same size; the active mass not only includes the heating surface, but also the surface of the liquid in contact with the tubular partition and the more active the circulation the greater will be the active mass of the liquid and the more rapid the evaporation.

Another application of greater interest is in the crystallization of massecuites. The surface of the crystals already existing may be regarded as the active mass on which sugar still in supersaturated solution will deposit. Hence crystallization will be more rapid the smaller the grain, because when the weight of sugar is the same a larger surface is offered when the number of crystals is greater. Thus if x and x_1 be the number crystals present in a quantity of massecuite, then (treating the crystals as sphere of diameter d and d_1) the surfaces are proportional to $\pi x d^2$ and $\pi x_1 d_1^2$; the volumes are proportional to $\frac{\pi}{6} x d^3$ & $\frac{\pi}{6} x_1 d_1^3$; when the weight of the crystals is the same $\frac{\pi}{6} x d^3 = \frac{\pi}{6} x_1 d_1^3$ or $d_1 = \left(\frac{x}{x_1}\right)^{1/3}$; whence evidently

$$\frac{\text{surface of } x \text{ spheres}}{\text{surface of } x_1 \text{ spheres}} = \frac{x_1 \left(\frac{x}{x_1}\right)^{2/3}}{x}$$

that is to say, the active mass and the rapidity with which sugar will deposit from supersaturated solution is proportional to the number of crystals and inversely proportional to the square of the cube root of the number of crystals. Arithmetically, let in unit quantity of massecuite, let there be 1 crystal in one case, and in a second let there be 2, the total weight of crystals being the same in both cases. If the surface of the crystals in the first case be put equal to 1, in the second case the surface will be $\frac{2}{1} \times \left(\frac{1}{2}\right)^{2/3} = 1.263$ i.e. doubling the number of crystals increases the area of the sides of the crystals 26.3%. If now a comparison be made between a massecuite cooled at rest and one cooled in motion (the number of crystals remaining the same in both cases), it will be at once apparent that the active mass is enormously increased by the natural motion of the crystals and mother liquor, a scheme so commonly applied in the crystallization in motion process.

the rate of change will be twice as fast as when there is only one unit present. Now, in a solution of cane sugar in the presence of an acid, let there be originally *a* parts of sugar present; in a very small interval, of time, *t*, let *x* parts be inverted or changed into invert sugar under the influence of the acid following the equation

$$\underset{\text{Cane Sugar}}{C_{12}H_{22}O_{11}} + \underset{\text{Water}}{H_2O} = \underset{\text{Dextrose}}{C_6H_{12}O_6} + \underset{\text{Levulose}}{C_6H_{12}O_6}$$

There are now present $(a - x)$ parts of sugar; since the rate of transformation is proportional to the active mass, which here is the amount of cane sugar still unchanged $\frac{dx}{dt} = k\,(a - x)$ where k is a constant.

By integration

$$\log \frac{a}{a - x} = k\,t$$

$$\text{or } \frac{1}{t} \log \frac{a}{a - x} = k$$

A solution of cane sugar when observed in the polariscope exhibits a rotation to the right. As inversion proceeds the rotation falls, and eventually when complete, exhibits a fixed left handed rotation. If the total change is represented by *a*, this quantity is proportional to the total amount of sugar originally present. The amount inverted at any moment is proportional to the difference between *a* and the fall in polarization. If this quantity be denoted by *x*, then the determination of the initial and final polarization and the polarization at any moment give data to calculate the constant deduced above and to test the validity of the law of mass action. Thus if the initial reading be 100 Ventzke degrees, the reading after complete inversion be 28°, and the reading after action has continued for 30 minutes, be 90 then

$a = 128$ and $x = 100 - 90 = 10$ and the constant will be

$$\frac{1}{30} \log \frac{128}{128 - 10} = .001178$$

the constant being expressed with reference to minutes and common logarithms. This law of mass action was tested and found correct by Wilhelmy in 1850.*

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* The development above refers to unimolecular reactions of which the inversion of cane sugar by acids is a typical example; very recently it has been suggested that the inversion of cane sugar is not a unimolecular reaction and that very slight deviations may occur. See Armstrong and Cadwell, *Proceedings of the Royal Society, 74, 195*; Julius Meyer, *Zeitschrift fur Physikalische Chemie, 62, 59*; and C. S. Hudson, *Journal of the American Chemical Society, 32, 885.*

RELATIVE STRENGTH OF ACIDS AS DETERMINED BY THE RATE OF INVERSION.—As soon as the theory of ionic dissociation had been propounded by Arrhenius in 1884, it was recognized by Ostwald that measurements of the rate of inversion of cane sugar by different acids under exactly equal conditions would also give a measure of the strength of the acid or in terms of the ionic hypothesis of the relative degree of dissociation, i.e., of the concentration of the hydrogen ions to the presence of which the ionic hypothesis attributes the peculiar properties of acids. Oswald[2] accordingly made determinations of the rate of inversion of many acids. His experimental procedure was as follows: equal quantities of a normal solution of an acid and of a 40%-50% solution of cane sugar were mixed and kept at a temperature of 25° C. After a suitable interval the polarization was observed and from this observation, combined with the initial and final polarizations, values of the constant $\frac{1}{t} \log \frac{a}{a-x}$ were obtained. The constants of some commonly occurring acids as found by Ostwald are given in the subjoined table. In the first column is given the value of the constant at 25° C. for half normal acids referred to common logarithims and time unit of minutes; in the second column are given values of the constant referred to hydrochloric acid as unity*.

	Value of $\frac{1}{t} \log \frac{a}{a-x}$	
Hydrochloric	.002187	100.0
Hydrobromic	.002438	111.4
Nitric	.002187	100.0
Sulphuric	.001172	53.6
Sulphurous	.000663	30.4
Oxalic	.000400	18.6
Phosphoric	.0001357	6.2
Acetic	.0000088	.4

These values make it possible to calculate the amount of sugar inverted at a temperature of 25° C. by acids in .5 normal concentration over any period and for any concentration of sugar solution; thus if it be required to find the amount of sugar inverted in a 20% solution by half normal sulphuric acid in one hour, the calculation would be as follows: putting the initial reading equal to 20, the final reading will be (at 25°) — 6.0; whence

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* The reference books at my disposal only generally give the figures in the second column, and when the actual constant is given it is quoted as 10,000 times as great as the figures I have given. An actual experiment with sulphuric acid in one-half normal solution gave: initial polarization, 60.0; final polarization, 18.0; polarization after 30 minutes, 53.9; whence $\frac{1}{30} \log \frac{78}{78-6.1} = k = .001179$.

$a = 26$, and $\frac{1}{60}$ log $\frac{26}{26-x}$ = .00172; whence $\frac{26}{a-x}$ = 1.1175; $x = 2.73$, which is the fall in polarization; the total fall being 26, the percentage of sugar inverted is $\frac{100 \times 2.73}{26}$ = 10.5%.

To the sugar manufacturer these figures are of indifferent interest; I therefore made determinations of the velocity of inversion of some acids in dilute solution at temperatures of 97° C.-98° C. The routine of the determinations was as follows: Twenty-five cubic centimeters of a 20% solution of cane sugar were placed in a 50 cc. flask; 5 cc. of a dilute acid were then placed in the flask and the volume completed to 50 cc.; the flasks and their contents were placed in a vessel of boiling water; when the temperature of the contents of the flasks reached 97° C., the time was taken; the flasks were allowed to remain for 30 minutes; the vessel was then removed from the lamp and the contents of the flasks rapidly cooled by running into the vessel a copious stream of cold water; the inversion was then almost instantaneously stopped, the contents of the flasks being polarized as soon as they reached the laboratory temperature, which took about four minutes. The results obtained were as follows, *t* being referred to minutes, the logarithms being common, and the concentration of the acid in all cases being $\frac{N}{1000}$.

Acid	Value of $\frac{1}{t} \log \frac{a}{a-x}$	
Hydrochloric	.0181	100.0
Nitric	.0180	99.9
Sulphuric	.0132	72.9
Sulphurous	.0088	48.6
Oxalic	.0077	42.7
Phosphoric	.0034	18.7
Acetic	.0012	6.4

THE EFFECT OF TEMPERATURE.—The rate at which the inversion of cane sugar—and of all similar reactions—proceeds is enormously increased with rise of temperature. Thus the velocity of reaction of $\frac{1}{1000}$ N hydrochloric acid is about nine times as great at 97° C.-98° C. as is the velocity of .5N hydrochloric acid at about 25° C. The effect of temperature has been studied by Urech and by Spohr and the following general equation has been found connecting velocity of reaction and temperature.

$$C_1 = C_0 \, e^{\frac{A\,(T_1 - T_0)}{T_0\,T_1}}$$

where C_1 and C_0 are the rates of inversion at temperatures T_0

and T_1 (both of course in the absolute scale); e is the base of the natural system of logarithm (= 2.71828 ....) and A is a constant, which is equal to 12820. Urech, to whom the above formula is due, found the following results:

Temperature of Reaction.	Rate of Inversion.
10	.217
25	9.67
40	73.4
45	139
50	268
55	491

It was shown by Sigmond[4] that this formula was also applicable up to 100° C. and according I have calculated values of the rate of inversion up to 100° C., putting the rate at 25° C. equal to unity.

Rate of Inversion	Temperature
1	25
7.6	40
14.3	45
26.7	50
57.7	55
91.8	60
162	65
282	70
483	75
814	80
1354	85
2110	90
3573	95
5659	100

EFFECT OF CONCENTRATION OF THE ACID.—Within narrow limits, the rate of inversion is proportional to the concentration of the acid; but as the differences in concentration become more pronounced, the direct proportionality tends to disappear. With the stronger acids there is a slight increase in the rate of inversion* in proportion to the amount of acid; with the weaker acids the reverse obtains. As none of the reference books available to me gave any data on this point, I determined under strictly comparative conditions the rate of inversion of hydrochloric acid in concentration from .2 N to .005 N, the routine of the experiment being as under: Ninety cubic centimeters of a solution of sugar was placed in a flask followed by 10 cc. of 2 N, 1.8 N, etc., hydrochloric acid. The flasks were allowed to stand at the laboratory temperature for a convenient interval, after which they were filled into tubes and polarized. The same interval was allowed between each observation as was taken in the operation of filling in 10 cc. of the acids. The results obtained were:

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* Under the ionic hypothesis the degree of dissociation increases with dilution, so that relatively there should be more hydrogen ions present in dilute than in concentrated solution, and the molecular rate of inversion should increase.

Hydrochloric Acid	Relative Velocity of Inversion Referred to Equimolecular Quantities
.2 N	1.000
.18 N	.970
.16 N	.956
.14 N	.938
.12 N	.928
.10 N	.912
.08 N	.899
.06 N	.887
.04 N	.868
.02 N	.857
.01 N	.851

Nitric Acid	Relative Velocity of Inversion Referred to Equimolecular Quantities
.25 N	1.000
.20 N	.946
.15 N	.909
.10 N	.870
.05 N	.837
.02 N	.824

Sulphuric Acid	Relative Velocity of Inversion Referred to Equimolecular Quantities
.5 N	1.000
.4 N	.939
.3 N	.922
.2 N	.915
.1 N	.880
.04 N	.863

Inversion in Pure Aqueous Solution at High Temperatue.—Cane sugar solution in water when kept at high temperatures gradually becomes inverted. Under the ionic hypothesis this is explained by regarding water itself as being very slightly dissociated into hydroxyl ions and hydrogen ions, under the influence of the latter of which the inversion occurs. This destruction of sugar has been, amongst others, most carefully studied by Kulgren[5]: he found that at first there was a very slow inversion of sucrose solutions at 100° C. As the heating progressed the rate of inversion gradually increased. He attributes the initial inversion to the action of the hydrogen ions and the increased rate of inversion later to the formation of acids arising from the invert sugar formed in the earlier stages. Amongst data of an experiment by Kulgren appear the following:

Initial polarization, 9.37; polarization after heating for 200 minutes, 9.34; then taking the final reading after heating as 2.81, the constant referred to a time unit of minutes is .0000015.

INVERSION OF CANE SUGAR UNDER THE INFLUENCE OF SALTS.—Under the influence of salts of weaker bases with strong acids, such as zinc nitrate, aluminum sulphate, etc., cane sugar is inverted. This inversion has been mainly studied by Long, who in some cases found the rate of inversion followed Wilhelmy's law, and in others that the rate of inversion either increased or decreased with the time. Under the ionic hypothesis this inversion is thus explained. With the salt of a strong acid and weak base, such as zinc nitrate, the solution of the salt gives rise to the following conditions:

The water is dissociated very slightly in hydrogen ions and into hydroxyl ions.

The salt dissociates largely into its anions and kations.

Then if the base is a weak one, so that its dissociation constant is small, the hydroxyl ions existing in the water will be taken up in the formation of the slightly ionized base and further dissociation of the water will result. The change taking place will be roughly given by the expression

$$B' + x' + HOH \rightleftarrows B.OH + x + H$$

so that a greater quantity of hydrogen ions exists than previously, and to the presence of these the inversion is attributed. Conversely, the solution of a salt of a strong base and weak acid will result in the accumulation of hydroxyl ions and an alkaline solution will result.

INFLUENCE OF NEUTRAL SALTS.—The influence of neutral salts on the rate of inversion of cane sugar has been chiefly examined by Arrhenius and developed by him under the ionic hypothesis. He found that the rate of inversion of cane sugar was increased by the simultaneous presence of certain neutral salts; e.g., the chlorides, bromides, and nitrates. Under the ionic hypothesis the addition of a neutral salt to a solution of its acid lowers the concentration of the hydrogen ions; and hence, on the hypothesis that the inversion of cane sugar—and other similar reactions—is due to the presence of hydrogen ions, the rate of inversion of cane sugar should be decreased by the presence of neutral salts. Arrhenius explains this diversion from the ionic hypothesis by the conception of an active and inactive form of cane sugar in solution, of which only the former enters into the change, and he assumes that the addition of a neutral salt increases the active mass of the cane sugar so much so that the decrease in the rate of inversion due to the dissociation in concentration of the hydrogen ion is more than counterbalanced, and that an increase in the rate of inversion occurs.

The salts used by Arrhenius were the chlorides of the alkalies and alkaline earths in connection with hydrochloric acid; potassium, sodium, and ammonium nitrate in connection with nitric acid; and potassium bromide and iodide in connection with their respective acids. Some of his results are given in the table below:

Concentration of Acid	Concentration of Salt	Temperaature	Constant Referred to Minutes x 10^4	Percentage Increase
.05 N hydrochloric acid	....	39.5	31.9	....
" " "	.4 N sodium chloride	39.5	36.3	25.3
" " "	.4 N lithium chloride	39.5	36.9	26.4
" " "	.4 N ammon. chloride	39.5	37.0	26.4
" " "	.4 N potassium chloride	39.5	36.4	24.4
" " "	.4 N calcium chloride	39.5	37.5	26.9
" " "	....	39.6	32.0	....
" " "	.4 N strontium chloride	39.6	36.2	20.1
" " "	.4 N barium chloride	39.6	36.6	22.2
" " "	.4 N magnes'm chloride	39.6	36.3	26.5
.05 N nitric acid	....	39.5	29.9	....
" " "	.4 N potassium nitrate	39.5	33.9	24.6
" " "	.4 N sodium nitrate	39.5	34.0	25.0
" " "	.4 N ammonium nitrate	39.5	34.3	26.1
.05 N hydrobromic acid	....	39.4	30.6	....
" " "	.4 N potassium bromide	39.4	38.2	35.5
.034 N hydriodic acid	....	39.4	20.6	....
" " "	.4 N potassium iodide	39.4	25.3	35.0

In calculating the percentage increase Arrhenius[6] proceeded thus: "A direct test showed that the rate of inversion at 39.5° C. by $\frac{1}{20}$ normal nitric acid is $29.9 \times 10 - 4$. By the addition of .4N potassium nitrate this figure is raised to the value of 33.9. The conductibility observed showed that the degree of dissociation of the acid is lessened 8.9% by this addition; so one would expect a rate of inversion in the solution containing potassium nitrate of $29.9 \times .911 = 27.2$. The actually observed rate of reaction is $33.9 = 1.25 \times 27.2$. The increase in the rate of reaction by the addition of .4N potassium nitrate therefore amounts to 25% of the calculated values, 27.2."

ACTION OF NON-CONDUCTORS.—Arrhenius[6] also made determinations of the effect of non-conductors on the rate of inversion, and found the effect very small. There is one non-conductor, the action of which is of great interest in the sugar factory, and that is glucose. My results being quite at variance with all previous work, the action of this body is treated of separately and in detail below.

THE ACTION OF NEUTRAL SALTS ON THE RATE OF INVERSION OF CANE SUGAR BY ACIDS.—In the pages above have been given such a survey of the present knowledge of the inversion of cane sugar as the somewhat restricted literature at my disposal allows. It was thought that some more detailed experimental study designed from the point of view of the sugar makers might be of some small value. In a cane juice there is present, besides cane sugar, varying quantities of glucose of inorganic and organic salts; amongst the first are found chlorides, sulphates, phosphates, and, when sulphur is used in manufacture, sulphites. The organic acids which are known to exist are oxalic, malic, succinnic, glycollic and acetic in damaged cane. In addition, lactic and saccharic acids are formed in process of manufacture. Of the organic acids, oxalic has a much greater inverting action than any of the others.

The bases which occur in cane juices are: lime, magnesia, potash, and soda. The acids, which are used in cane sugar manufacture, are sulphurous and phosphoric. So far then, as regards the manufacture of cane sugar, it might perhaps appear to be sufficient to have studied the action of sulphurous and phosphoric acids in the presence of the salts mentioned above. However, to obtain a broader view of the subject, I made experiments on the action of the following bodies; the chlorides and nitrates of the alkalies and alkaline earths, and the sulphates and phosphates of the alkalies, using as acids phosphoric, oxalic, hydrochloric, sulphuric and sulphurous. The first series of experiments were arranged as follows:

Twenty-five cubic centimeters of a 20% solution of cane sugar were placed in a 50 cc. flask. To this was then added varying quantities of a solution of a known concentration of the salt under examination, and a fixed quantity, 5 cc. of the acid. The contents were then placed in a vessel of boiling water. The time was taken when the contents of the flasks had reached 97°, after which they were kept at this temperature for 30 minutes. They were then rapidly cooled. In this series, working with dilute acids, inversion stopped practically on cooling; nevertheless, the contents of the flasks were polarized as soon as cool. The first series of experiments was made with hydrochloric acid of strength .01 normal, of which 5 cc. was used for the inversion in 50 cc. total volume of solution, the concentration thus being .001 N.

Before giving the results of the experiments, the following explanations are necessary. At first I found it impossible to obtain duplicates in any way agreeing with each other. This was found to be due to alkali dissolved from the flasks which behaved very unevenly in this respect. After digesting all the flasks with strong hydrochloric acid, much more even, though not entirely satisfactory, results were obtained. With each batch of experiments a check with acid alone was performed. With fourteen such checks, I obtained a reading in a Ventzke scale polariscope of from 2.2 to 5.4° Ventzke, the initial reading being in all cases 39.4°. I was unable to obtain closer duplicates than this. Each experiment with the addition of salts was done twice, and the average of the two determinations is given in the tables below:

Effect of neutral salts in dilute solution on the rate of inversion of cane sugar by .001 normal hydrochloric acid at a temperature of 97° C. to 98° C. Initial reading of sugar solution 39.4° Ventzke. Reading after complete inversion, —11.0° Ventzke; time of heating, 30 minutes; in the absence of salts, the reading after 30 minutes' heating varied from 2.4° to 4.5° Ventzke.

Salt and Concentration		Polariscope Reading
Potassium chloride	.002 N	3.4
“	.005 N	4.7
“	.01 N	3.7
“	.02 N	4.0
Sodium chloride	.002 N	3.8
“	.005 N	4.4
“	.01 N	4.8
“	.02 N	4.4
Ammonium chloride	.002 N	4.4
“	.005 N	2.8
“	.01 N	2.6
“	.02 N	3.1
Calcium chloride	.002 N	3.2
“	.005 N	4.1
“	.01 N	3.2
“	.02 N	4.2
Strontium chloride	.002 N	3.0
“	.005 N	2.8
“	.01 N	2.8
“	.02 N	4.4
Barium chloride	.002 N	2.2
“	.005 N	4.8
“	.01 N	3.8
“	.02 N	3.7

Salt and Cencentration		Polariscope Reading
Potassium bromide	.002 N	4.2
"	.005 N	3.8
"	.01 N	3.3
"	.02 N	3.8
Potassium iodide	.002 N	3.2
"	.005 N	2.8
"	.01 N	3.6
"	.02 N	4.8
Potassium nitrate	.002 N	3.4
"	.005 N	3.2
"	.01 N	2.9
"	.02 N	3.6
Sodium nitrate	.002 N	4.4
"	.005 N	5.0
"	.01 N	3.8
"	.02 N	5.0
Ammonium nitrate	.002 N	3.4
"	.005 N	3.2
"	.01 N	3.3
"	.02 N	3.9
Magnesium nitrate	.002 N	4.1
"	.005 N	3.7
"	.01 N	5.0
"	.02 N	3.4
Calcium nitrate	.002 N	3.7
"	.005 N	2.8
"	.01 N	3.6
"	.02 N	3.6
Strontium nitrate	.002 N	3.4
"	.005 N	3.8
"	.01 N	3.2
"	.02 N	3.2
Barium nitrate	.002 N	4.0
"	.005 N	3.2
"	.01 N	3.1
"	.02 N	3.1
Potassium sulphate	.002 N	14.1
"	.005 N	18.4
"	.01 N	25.9
"	.02 N	29.6
Sodium sulphate	.002 N	14.4
"	.005 N	20.6
"	.01 N	25.6
"	.02 N	30.1

Salt and Cencentration		Polariscope Reading
Magnesium sulphate	.002 N	11.0
“	.005 N	15.5
“	.01 N	21.7
“	.02 N	26.2
Calcium sulphate	.002 N	12.1
“	.005 N	19.2
“	.01 N	22.0
“	.02 N	26.0
Ammonium sulphate	.002 N	14.4
“	.005 N	19.2
“	.01 N	25.4
“	.02 N	30.2
Potassium oxalate	.001 N	5.8
“	.0025 N	9.7
“	.005 N	16.4
“	.01 N	36.9
Sodium oxalate	.001 N	6.4
“	.0025 N	8.8
“	.005 N	17.7
“	.01 N	35.0
Ammonium oxalate	.001 N	7.2
“	.0025 N	10.0
“	.005 N	18.2
“	.01 N	36.4
Potassium acetate	.0002 N	9.2
“	.0005 N	19.2
“	.001 N	35.2
“	.002 N	39.2
Sodium acetate	.002 N	8.4
“	.0005 N	18.8
“	.001 N	36.0
“	.002 N	39.2
Calcium acetate	.0002 N	9.0
“	.0005 N	18.6
“	.001 N	35.0
“	.002 N	38.8
Magnesium acetate	.0002 N	8.8
“	.0005 N	18.9
“	.001 N	36.5
“	.008 N	38.9
Barium acetate	.002 N	9.1
“	.005 N	19.9
“	.001 N	35.1
“	.002 N	38.8

Effect of neutral salts in dilute solution on the rate of inversion of cane sugar by .001 normal sulphuric acid, at a temperature of 97°-98°C. Initial reading of sugar solution 39.4° Ventzke. Reading after complete inversion, —11.0° Ventzke; time of heating, 30 minutes; in the absence of salts this reading, after 30 minutes' heating, varied from 8.9° to 9.3° Ventzke.

Salt and Concentration		Polariscope Reading
Potassium chloride	.002 N	8.7
“	.005 N	9.2
“	.01 N	9.1
“	.02 N	8.5
Sodium chloride	.002 N	8.9
“	.005 N	8.7
“	.01 N	8.7
“	.02 N	8.3
Ammonium chloride	.002 N	9.1
“	.005 N	8.6
“	.01 N	8.6
“	.02 N	8.6
Magnesium chloride	.002 N	9.0
“	.003 N	8.6
“	.01 N	9.2
“	.02 N	9.2
Calcium chloride	.002 N	8.7
“	.005 N	8.7
“	.01 N	8.8
“	.02 N	9.0
Potassium bromide	.002 N	9.3
“	.005 N	9.3
“	.01 N	9.3
“	.02 N	8.4
Potassium iodide	.002 N	9.3
“	.005 N	9.3
“	.01 N	8.8
“	.02 N	9.3
Potassium nitrate	.002 N	8.4
“	.005 N	9.2
“	.01 N	8.6
“	.02 N	8.8
Ammonium nitrate	.002 N	8.8
“	.005 N	8.6
“	.01 N	8.6
“	.01 N	8.8

Salt and Cencentration		Polariscope Reading
Sodium nitrate	.002 N	8.6
‘‘	.005 N	9.1
‘‘	.01 N	9.1
‘‘	.02 N	8.8
Magnesium nitrate	.002 N	9.2
‘‘	.005 N	8.8
‘‘	.01 N	9.4
‘‘	.02 N	8.9
Calcium nitrate	.002 N	8.4
‘‘	.005 N	8.8
‘‘	.01 N	8.6
‘‘	.02 N	8.4
Potassium sulphate	.002 N	10.0
‘‘	.005 N	17.8
‘‘	.01 N	24.2
‘‘	.02 N	28.5
Sodium sulphate	.002 N	10.0
‘‘	.005 N	17.5
‘‘	.01 N	24.2
‘‘	.02 N	28.6
Ammonium sulphate	.002 N	10.8
‘‘	.005 N	17.2
‘‘	.01 N	23.1
‘‘	.02 N	27.4
Sodium sulphite	.001 N	9.0
‘‘	.0025 N	12.0
‘‘	.005 N	15.1
‘‘	.01 N	21.2
Potassium oxalate	.001 N	13.5
‘‘	.0025 N	21.2
‘‘	.005 N	35.2
‘‘	.01 N	39.4
Sodium oxalate	.001 N	13.5
‘‘	.0025 N	21.2
‘‘	.005 N	35.7
‘‘	.01 N	39.2
Potassium acetate	.0002 N	15.1
‘‘	.0005 N	24.7
‘‘	.001 N	35.3
‘‘	.002 N	39.3
Sodium acetate	.0002 N	14.4
‘‘	.0005 N	21.7
‘‘	.001 N	34.3
‘‘	.002 N	39.3

Salt and Concentration		Polariscope Reading
Magnesium acetate	.0002 N............	15.1
“	.0005 N............	23.7
“	.001 N............	33.7
“	.002 N............	39.3
Calcium acetate	.0002 N............	15.7
“	.0005 N............	24.0
“	.001 N............	34.0
“	.002 N............	37.3

Effect of neutral salts in dilute solution on the rate of inversion of cane sugar by .01 normal oxalic acid, at a temperature of 97°-98°C. Initial reading of sugar solution 39.4° Ventzke; reading after complete inversion —11.0° Ventzke; time of heating, 30 minutes; in the absence of salts the reading, after 30 minutes' heating, varied from —9.0° to —9.5° Ventzke.

Salt and Concentration		Polariscope Reading
Potassium chloride	.002 N............	—9.7
“	.005 N............	—9.4
“	.01 N............	—9.7
“	.02 N............	—9.4
Sodium chloride	.002 N............	—9.4
“	.005 N............	—9.4
“	.01 N............	—9.7
“	.02 N............	—9.4
Magnesium chloride	.002 N............	—9.6
“	.005 N............	—9.4
“	.01 N............	—9.7
“	.02 N............	—10.0
Potassium bromide	.002 N............	—8.9
“	.005 N............	—9.0
“	.01 N............	—9.1
“	.02 N............	—9.1
Potassium iodide	.002 N............	—8.9
“	.005 N............	—9.2
“	.01 N............	—9.2
“	.02 N............	—8.9
Potassium nitrate	.002 N............	—9.2
“	.005 N............	—9.4
“	.01 N............	—9.6
“	.02 N............	—9.4
Sodium nitrate	.002 N............	—9.3
“	.005 N............	—9.4
“	.01 N............	—9.6
“	.02 N............	—9.4

Salt and Concentration		Polariscope Reading
Ammonium nitrate	.002 N............	—8.8
“	.005 N............	—8.9
“	.01 N............	—9.0
“	.02 N............	—8.9
Potassium sulphate	.002 N............	—5.9
“	.005 N............	—1.0
“	.01 N............	6.3
“	.02 N............	15.3
Sodium sulphate	.002 N............	—6.7
“	.005 N............	—1.0
“	.01 N............	6.5
“	.02 N............	14.9
Ammonium sulphate	.002 N............	—6.0
“	.005 N............	—1.6
“	.01 N............	5.8
“	.02 N............	14.6
Magnesium sulphate	.002 N............	—7.2
“	.005 N............	—4.6
“	.01 N............	3.2
“	.02 N............	10.8

Effect of neutral salts in dilute solution on the rate of inversion of cane sugar by .01 normal phosphoric acid, at a temperature of 97° C.-98° C. Initial reading of sugar solution 39.4° Ventzke; reading after complete inversion—11.0° Ventzke; time of heating, 30 minutes; in the absence of salts the reading, after 30 minutes, varied from —.4° to —.8° Ventzke.

Salt and Concentration		Polariscope Reading
Potassium chloride	.002 N............	1.0
“	.005 N............	.4
“	.01 N............	1.0
“	.02 N............	.8
Ammonium chloride	.002 N............	.4
“	.005 N............	.8
“	.01 N............	.4
“	.02 N............	.7
Potassium nitrate	.002 N............	.7
“	.005 N............	.2
“	.01 N............	.8
“	.02 N............	.7
Ammonium nitrate	.002 N............	.6
“	.005 N............	.6
“	.01 N............	.6
“	.02 N............	.4

Salt and Cencentration		Polariscope Reading
Sodium sulphate	.002 N	7.2
"	.005 N	14.7
"	.01 N	21.4
"	.02 N	28.3
Ammonium sulphate	.002 N	7.2
"	.005 N	12.1
"	.01 N	19.4
"	.02 N	25.3
Potassium oxalate	.001 N	4.2
"	.0025 N	8.2
"	.005 N	19.7
"	.01 N	37.4

Effect of neutral salts in dilute solution on the rate of inversion of cane sugar by .01 normal acetic acid, at a temperature of 97°C.-98° C. Initial reading of sugar solution 39.4° Ventzke; reading after complete inversion —11.0° Ventzke; time of heating, 30 minutes; in the absence of salts the reading, after 30 minutes, varied from 27.2° to 28.0° Ventzke.

Salt and Concentration		Polariscope Reading
Sodium chloride	.002 N	27.7
"	.005 N	27.5
"	.01 N	27.2
"	.02 N	27.4
Barium chloride	.002 N	27.7
"	.005 N	27.7
"	.01 N	27.0
"	.02 N	26.5
Potassium bromide	.002 N	27.0
"	.005 N	27.1
"	.01 N	26.4
"	.02 N	27.7
Potassium iodide	.002 N	28.7
"	.005 N	27.7
"	.01 N	27.3
"	.02 N	27.3
Potassium nitrate	.002 N	27.4
"	.005 N	27.5
"	.01 N	27.7
"	.02 N	27.4
Sodium sulphate	.002 N	29.5
"	.005 N	31.4
"	.01 N	33.2
"	.02 N	34.5

Salt and Cencentration		Polariscope Reading
Magnesium sulphate	.002 N	28.6
“	.005 N	30.1
“	.01 N	31.1
“	.02 N	32.2
Sodium acetate	.002 N	31.8
“	.005 N	33.8
“	.001 N	35.7
“	.002 N	37.2

The results of this series of experiments may be thus summarized:

1. In concentration up to .02 N, the chlorides, bromides, and iodides of the alkalies and alkaline earths have no effect on the rate of inversion of cane sugar by hydrochloric, sulphuric, oxalic, phosphoric, or acetic acids.
2. The sulphates, oxalates, sulphites, and acetates materially retard inversion in dilute solution. The retardation is evidently connected with the strength of the acid as understood in the ionic hypothesis.
3. The retardation increases with the amount of salt present; but owing to experimental imperfections, no attempt is made to deduce any law from this series.
4. No difference is detectable as regards the action of the bases of the alkalies and alkaline earths.
5. Ammonium salts in dilute solution at the temperature of boiling water behave precisely as the salts of the alkalies and alkaline earths.

ACTION OF CHLORIDES OF THE ALKALIES IN CONCENTRATED SOLUTION.—To make trial of this point, I made an experiment of the effect of sodium chloride in more concentrated solution on the rate of inversion of very dilute hydrochloric acid, and obtained the following results:

The initial reading of the sugar solution was 40.8. After half an hour's heating at 97° C. to 98° C. in the presence of $\frac{N}{500}$ hydrochloric acid and the quantity of sodium chloride as shown below the polarizations were:

Concentration of Salt.	Polarization.
0	— 7.4
.08 N	— 8.1
.2 N	— 8.8
.4 N	— 9.4
.8 N	— 9.8
1 N	—10.1

Hence with more concentrated solutions of chloride the acceleration of the salt on inversion is readily detectable.

THE ACTION OF SALTS IN CONCENTRATED SOLUTION ON THE RATE OF INVERSION OF CANE SUGAR AT ORDINARY TEMPERATURES UNDER THE INFLUENCE OF ACIDS IN MORE CONCENTRATED SOLUTIONS.—Although such a state of affairs as indicated in the above heading does not ever obtain in the process of manufacture of cane sugar, yet I thought some little time thereon spent might not be altogether wasted, since the influence of alkali dissolved from the flasks used, could be thus eliminated.

The experiments, the results of which are given below, were made as follows: Twenty-five cubic centimeters of a solution of cane sugar and 20 cc. of a 2 N solution of salt were placed in a 50 cc. flask. These flasks and their contents were allowed to stand over night to ensure all being at the same temperature. There was then added to each 5 cc. of 2 N acid, the flasks being shaken after the addition. Between the addition of the acid to each flask one minute was allowed to elapse. On taking the polariscope reading, one minute was also allowed to elapse between each reading so that the time interval was the same in all cases.

Three series of experiments gave the results as shown in the following table:

Concentration of Acid and of Salt.	Rate of Inversion.		
	I.	II.	III.
.2 N hydrochloric acid	1.000	1.000	1.000
“ plus .8 N lithium chloride	1.423	1.403	1.446
“ “ “ sodium chloride	1.380	1.410	1.414
“ “ “ potassium chloride	1.373	1.389	1.393
“ “ “ ammonium chloride	1.342	1.371	1.362
“ “ “ magnesium chloride	1.370	....	1.393
“ “ “ calcium chloride	1.376	....	1.404
“ “ “ strontium chloride	1.376	....	1.396
“ “ “ barium chloride	1.370	....	1.393
“ “ “ lithium bromide	1.539	1.566	1.567
“ “ “ sodium bromide	1.550	1.559	1.578
“ “ “ potassium bromide	1.506	1.559	1.532
“ “ “ ammonium bromide	1.486	1.506	1.510
“ “ “ magnesium bromide	1.500	....	....
“ “ “ calcium bromide	1.527	....	....
“ “ “ strontium bromide	1.520	....	....
“ “ “ barium bromide	1.500	....	....
“ “ “ lithium iodide	...	1.640	....
“ “ “ sodium iodide	1.633	1.640	1.647
“ “ “ potassium iodide	1.668	1.640	1.684
“ “ “ ammonium iodide	1.645	1.640	1.659
“ “ “ calcium iodide	1.699	....	....
“ “ “ barium iodide	1.664	....	....

The increase in the rate of inversion in the above table is expressed differently from that in the results due to Arrhenius and quoted on page 13. I have not attempted to determine (under the ionic hypothesis) the reduction in the concentration of the hydrogen ions due to the neutral salt, assuming indeed the existence of such bodies; the results shown above give the actual increase in the rate of inversion and not what the increase would be assuming that it is the hydrogen ions to which the inversion is solely due.

The conclusions to be drawn from this series of experiments are as follows:

1. The chlorides, bromides, and iodides of the alkali and alkaline earths, in solutions of about normal strength, accelerate the rate of inversion of cane sugar.
2. The influence of the bases is very nearly the same in all cases for the metals of the alkalies and alkaline earths.
3. There is a progressive rise in the increase of the rate of inversion from chlorides to bromides, and from bromides to iodides.
4. Taking the rate of inversion due to .2N Hydrochloric acid as equal to unity and taking the average in each series of all the chlorides, bromides and iodides, the following results are obtained:

Velocity of reaction	I.	II.	III.	Average.
due to .2 N H cl	1.000	1.000	1.000	1.000
" + .8 N chloride	1.380	1.394	1.409	1.394
" + .8 N bromide	1.528	1.547	1.548	1.542
" + .8 N iodide	1.662	1.640	1.666	1.656

In the series of experiments with dilute acids and salts a connection between the strength of an acid and the retardation of the rate of inversion by its salts was noted. It then became a matter of some interest to determine the relative rates of inversion due to hydrochloric, hydrobromic, and hydriodic acids. The reference books at my disposal gave the rate of inversion of cane sugar by hydrobromic acid as 1.14, that of hydrochloric acid being taken as unity. No mention was made of the rate of inversion of cane sugar by hydriodic acid. I accordingly prepared hydrobromic and hydriodic acids, and made a comparison of the rate of inversion of these acids, using the routine already described (p. 10):

Rate of inversion of .2 N hydrochloric acid	1.000
" " " .2 N hydrobromic "	1.054
" " " .2 N hydriodic "	1.103

INCREASE IN VELOCITY OF INVERSION DUE TO THE PRESENCE OF NITRATES.—The strength of hydrochloric acid (in the ionic sense) being the same as that of nitric acid, it was of some interest to compare the increase in the rate of inversion due to the presence of nitrates. Using the chlorides and nitrates of sodium, potassium, and ammonium in .8 normal solution, and hydrochloric acid in .2 normal solution, I obtained the following results:

	Series I.	Series II.
Velocity of inversion due to chlorides	1.000	1.000
Velocity of inversion due to nitrates	1.008	.996

ACTION OF SULPHATES.—A series of experiments made with sulphates exactly as described on page 24, gave the following results:

Concentration of Acid and of Salt.		Rate of Inversion.
.2 N hydrochloric acid		1.000
"	plus .8 N lithium sulphate	.347
"	" .8 N sodium sulphate	.352
"	" .8 N potassium sulphate	.360
"	" .8 N ammonium sulphate	.342
"	" .8 N magnesium sulphate	.412

Whereas with the halides no difference was detected as between the action of the salts of the alkalies and of the alkaline earths, the retardation due to magnesium sulphate was distinctly less than that due to the sulphates of the alkalies; this result was obtained in duplicate.

INFLUENCE OF VARYING AMOUNTS OF SALT ON THE RATE OF INVERSION.—The results I gave previously on page 23 showed that with an increasing amount of neutral salt the retardation of the rate of inversion increased. Owing to the presence of uncontrollable experimental errors, this series was not suitable for obtaining an expression of the nature of this increase. I accordingly examined this action in more concentrated solutions, allowing the inversion to take place in the cold. The experiments were made as follows:

Fifty cubic centimeters of a sugar solution, 5, 10, 15, 20, 25, cc. of a solution of the salt in question and 10 cc. of acid were placed in Ehrlenmeyer flasks together with sufficient water to complete the volume to 100 cc. All solutions had been made up 24 hours previously, so that all were at the same temperature. After a suitable interval polariscope tubes were filled and the reading taken. Readings were then taken at intervals of about 2 hours until five readings had been taken. As before, an interval of one minute was allowed between placing the acid in each flask and between the corresponding readings. The initial reading and final reading required for the calculation of the constant were obtained in separate solutions, the initial reading, however, being taken in the absence of acid.

ACTION OF AMMONIUM NITRATE ON THE RATE OF INVERSION OF CANE SUGAR BY .2 NORMAL NITRIC ACID AT ± 27° C.

Concentration of Salt.	Velocity of Reaction.	Acceleration due to Presence of Salt.	Acceleration ÷ Concentration.
0	1.000	....	...
.5	1.215	.215	.407
N	1.399	.399	.399
1.5 N	1.603	.603	.402
2.0 N	1.804	.804	.402
2.5 N	2.060	1.060	.424

ACTION OF SODIUM NITRATE ON THE RATE OF INVERSION OF CANE SUGAR BY .2 NORMAL HYDROCHLORIC ACID AT ± 27° C.

Concentration of Salt.	Velocity of Reaction.	Acceleration due to Presence of Salt.	Acceleration ÷ Concentration.
0	1.000	....	...
.5 N	1.210	.210	405
N	1.443	.443	443
1.5 N	1.650	.650	.433
2.0 N	1.956	.956	.478
2.5 N	2.195	1.195	.478

ACTION OF SODIUM CHLORIDE ON THE RATE OF INVERSION OF CANE SUGAR BY .2 NORMAL HYDROCHLORIC ACID AT ± 27° C.

Concentration of Salt.	Velocity of Reaction.	Acceleration due to Presence of Salt.	Acceleration ÷ Concentration.
0	1.000	....	...
.5 N	1.207	.207	.403
N	1.415	.415	.415
1.5 N	1.615	.615	.410
2.0 N	1.913	.913	.456
2.5 N	2.187	1.187	.475

ACTION OF AMMONIUM SULPHATE ON THE RATE OF INVERSION OF CANE SUGAR BY .2 NORMAL NITRIC ACID AT + 27° C.

Concentration of Salt.	Velocity of Reaction.	Retardation due to Salt.	Retardation ÷ $\sqrt[4]{\text{Concentration}}$.
0	1.000	....	...
.5 N	.443	.557	.662
N	.282	.718	.718
1.5 N	.230	.770	.656
2.0 N	.208	.792	.664
2.5 N	.196	.804	.645

ACTION OF SODIUM SULPHATE ON THE RATE OF INVERSION OF CANE SUGAR BY .4 NORMAL SULPHURIC ACID AT + 27° C.

Concentration of Salt.	Velocity of Reaction.	Retardation due to Salt.	Retardation ÷ $\sqrt[4]{\text{Concentration}}$.
0	1.000	....	...
.2 N	.560	.440	.692
.4 N	.415	.585	.732
.6 N	.360	.640	.726
.8 N	.323	.677	.715
N	.304	.696	.696

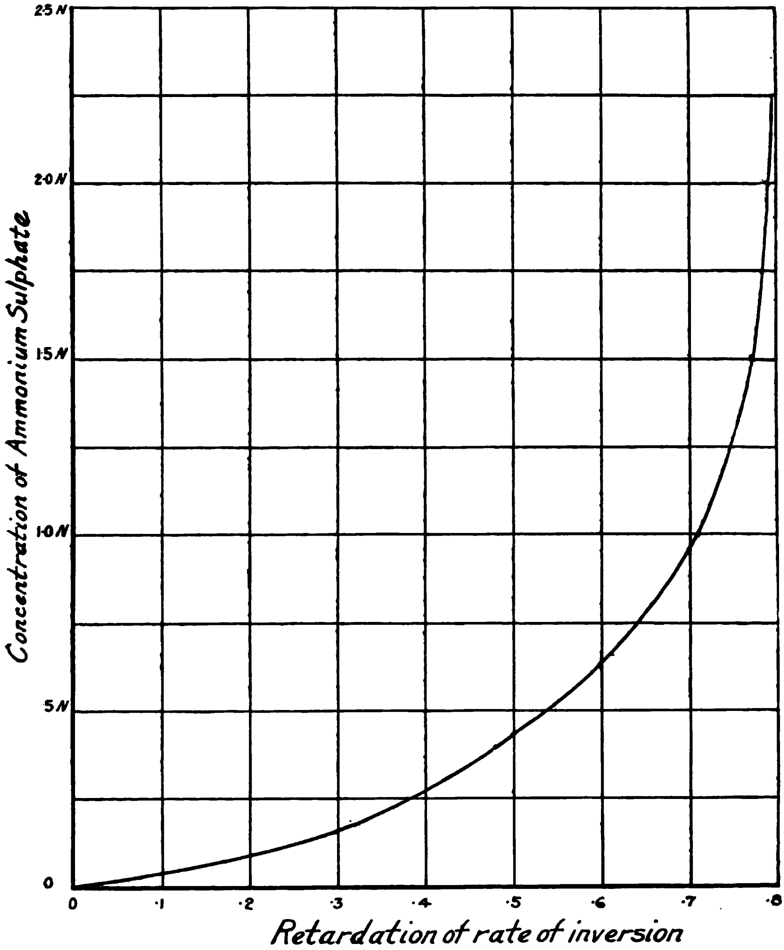
Inspection of these results show that with the chlorides and nitrates the acceleration of the rate of inversion is proportional to the concentration of the salt; with the sulphates, however, the retardation of the rate of inversion increased less rapidly than does the concentration; trial and error showed that approximately the relation $\frac{\text{Retardation}}{\sqrt[4]{\text{Concentration}}}$ = constant held.

As this series did not cover a very wide limit in the concentration of salt, I then made a series of determinations with .2 N hydrochloric acid and ammonium sulphate in concentration from .1 N to 2.5 N. It was found that the relation $\frac{\text{Retardation}}{\sqrt[4]{\text{Concentration}}}$ = constant held from .5 N to 2.5 N; between .1 N and .2 N retardation is proportional to the concentration of the salt.

The results are given in the following table and graphically in the curve in the annexed figure:

Concentration of Salt.	Velocity of Reaction.	Retardation due to Salt.	Retardation ÷ $\sqrt[4]{\text{Concentration}}$
0	1.000	....	...
.1 N	.833	.167	.297
.2 N	.687	.317	.443
.4 N	.523	.467	.600
.5 N	.450	.550	.698
.6 N	.405	.595	.703
.8 N	.338	.662	.702
N	.293	.707	.707
1.5 N	.225	.775	.702
2.0 N	.192	.808	.679
2.5 N	.184	.816	.648

THE ACTION OF GLUCOSE ON THE INVERSION OF CANE SUGAR.—In a classical series of papers dealing with the formation of molasses, Prinsen Geerligs[7] had occasion to investigate very closely the action of glucose on the inversion, particularly as contradictory results had been found by earlier investigators. He investigated, amongst others the action of the following salts: sodium chloride, potassium chloride, potassium bromide, potassium iodide, sodium sulphate, potassium nitrate, barium nitrate, magnesium sulphate, magnesium chloride,—all of which he found caused inversion of cane sugar when heated to the temperature of boiling water in the presence of glucose. The salts of ammonia, including the chloride, nitrate, sulphate and oxalate, inverted cane



sugar on heating both in the absence and in the presence of glucose. In his experiments he used the following proportions of sucrose and of glucose:

49% sucrose	50% water	1% glucose
34% “	33% “	33% “
50% “	50% “	
49.5% “	50% “	5% “
45% “	50% “	5% “
40% “	35% “	25% “

Invariably in the presence of glucose he found very considerable quantities of sugar inverted which increased with the amount of glucose present and was most pronounced with magnesium chloride and barium nitrate. In his experiments the salts were present in quantity about 6% on the weight of the whole solution. This invertive action of salts and glucose he explains as due to glucose having the properties of a weak acid, and in the case of sodium chloride, for example, setting free a minute trace of hydrochloric acid to which the inversion is due.

In my experiments I had always found a retarding action in the case of sulphates,—that is to say in so far as regards the action of the sulphates of the alkalies and the inversion of cane sugar,—they are to be regarded as alkaline salts. Accordingly, I thought then that the action of glucose and salts on cane sugar at high temperatures would bear examination. I then prepared approximately 50% solutions of sucrose and glucose, and of these I mixed equal quantities. Quantities of salts equal to normal weight in 110 cc. were then weighed out into ordinary sugar flasks and the salts were dissolved in the mixed sugar and glucose solution and the volumes completed to 110 cc. From these solutions carefully calibrated 50 cc. flasks were filled. One of these served as the blank, and one was maintained in a water bath at the temperature of boiling water for thirty minutes. Both check and heated solutions were then transferred to carefully calibrated litre flasks, and the glucose determined in 20 cc. of the diluted material. The results I found were as follows:

Salt.	Glucose per 1 cc. Original Solution Before Heating.	Glucose per 1 cc. Original Solution After Heating.
Sodium chloride	.2655	.2674
Sodium nitrate	.2624	.2649
Potassium chloride	.2649	.2647
Potassium nitrate	.2629	.2626
Potassium iodide	.2554	.2547
Magnesium chloride	.2568	.2587
Magnesium sulphate	.2694	.2712
Sodium sulphate	.2497	.2453

The inference from this experiment, which was repeated in duplicate with similar results, is that the inversion of cane sugar at high temperatures under the combined influence of glucose and neutral salts does not happen. Geerligs used invert sugar in his experiments and in those described above I had employed Khalbaum's c.p. dextrose. Thinking that the inversion observed by Geerligs might have been due to the levulose of the invert sugar, I inverted a 50% solution of sucrose by heating it with sulphuric acid in .2 N concentration. The temperature was not allowed to rise above 70° C. and a pale yellow invert sugar syrup resulted. This was neutralized with barium carbonate, boiled to expel carbonic dioxide, and filtered free from the precipitated sulphate and excess of carbonate. Equal quantities of this solution and a 50% sucrose solution were mixed and normal weight of different salts dissolved in the mixture as previously described. The results I obtained were as follows:

Salt.	Invert Sugar per 1 cc. Original Solution Before Heating.	Invert Sugar per 1 cc. Original Solution After Heating.
Sodium nitrate	.2375	.2371
Potassium nitrate	.2412	.2409
Sodium chloride	.2415	.2415
Potassium chloride	.2418	.2398
Sodium sulphate	.2154	.2120
Magnesium sulphate	.2286	.2284

From these two series of determinations only one conclusion is to be drawn, and that is that the inversion of cane sugar under the combined influence of dextrose or levulose does not exist.

The Action of Ammonium Salts on Inversion.—It is well known that solutions of ammonium salts on boiling become acid and have an invertive effect on cane sugar.

The following data were found with a concentration of ammonium salt of .2 N and heating at a temperature of 97° C.-98° C. for 60 minutes, the constant being expressed with reference to common logarithms, and a time unit of minutes:

Salt.	
Ammonium nitrate	.00145
Ammonium chloride	.00153
Ammonium bromide	.00178
Ammonium sulphate	.00023

After an hour's heating at this temperature the solutions were still neutral to azolitmin paper, and it was found possible to obtain inversion of cane sugar after the addition of sufficient ammonia to impart an alkaline reaction to the solution, this alkaline reaction being still apparent after heating for an hour. Previously it had been found that dilute solutions of ammonium sulphate at high temperatures retarded inversion, and concentrated solutions also retarded inversion at low temperatures, and that dilute solutions of the halides and nitrates had no appreciable effect at high temperatures, and an accelerating effect in concentrated solution at low temperatures. In fact, in every way they were similar in action to the salts of the alkalies.

Now, since concentrated solutions of ammonium sulphate in the cold retard inversion, and at elevated temperatures invert of themselves, there must be some temperature at which ammonium sulphate must, so far as regards the inversion of cane sugar, be regarded as a neutral salt. In the language of the ionic hypothesis ammonium sulphate must, dependent on temperature either diminish the amount of hydrogen ions or increase their number. From another point, the action of ammonium salts is very peculiar. In the development of the ionic hypothesis ammonia is regarded as a very weak base when compared with the alkalies, its relative strength being but 2, when that of lithia is put equal to 100. Now, the results I have obtained point towards there being a connection between the strength of the acid and the effect exerted by the salt. Conversely, a similar relation would be expected when the nature of the base varies; that this is so is from the experiments as the inversion of cane sugar by salts due to Long[8]. It would then be expected that ammonium salts would have a very different effect from the salts of the alkalies. Actually, their effect is very similar in dilute solutions at high temperatures and in concentrated solutions at low temperatures. Looked at in this way, ammonia must be regarded as a base of similar strength to the alkalies.

THE EFFECT OF NEUTRALIZATION OF AN ACID ON THE RATE OF INVERSION.—It follows from the experiments described above that if a solution of cane sugar in the presence of a halide acid or of nitric acid be partly neutralized that the rate of inversion will not decrease in proportion to the amount neutralized. Conversely, in the presence of sulphuric acid or of most other acids neutralization of a part of the acid will decrease the rate of inversion in greater proportion than the amount neutralized. This is seen in the following experiments:

1. To 25 cc. of sugar solution contained in a 50 cc. flask, five lots of 10 cc. of N. hydrochloric acid were added. This was immediately followed by 2, 4, 6, 8 cc. of N soda; to four other similar flasks 2, 4, 6, 8 cc. of N hydrochloric acid were added. The contents of the flasks were at once filled to 50 cc. and polarized after a suitable interval. The results obtained were:

HYDROCHLORIC ACID.

C. c. N acid per 50 c. c.	C. c. N alkali per 50 c. c.	Free Acid.	Velocity of Inversion.
10	0	10	1.000
10	2	8	.905
10	4	6	.705
10	6	4	.443
10	8	2	.253
8	0	8	.779
6	0	6	.564
4	0	4	.380
2	0	2	.176

SULPHURIC ACID.

C. c. N acid per 50 c. c.	C. c. N alkali per 50 c. c.	Free Acid.	Velocity of Inversion.
10	0	10	1.000
10	2	8	.676
10	4	6	.468
10	6	4	.285
10	8	2	.057
8	0	8	.808
6	0	2	.562
4	0	4	.333
2	0	2	.198

OXALIC ACID.

C. c. N acid per 50 c. c.	C. c. N alkali per 50 c. c.	Free Acid.	Velocity of Inversion.
10	0	10	1.000
10	2	8	.615
10	4	6	.198
10	6	4	.024
10	8	2	0
8	0	8	.785
6	0	6	.540
4	0	4	.343
2	0	2	.164

PHOSPHORIC ACID.

C. c. N acid per 50 c. c.	C. c. N alkali per 50 c. c.	Free Acid.	Velocity of Inversion.
10	0	10	1.000
10	2	8	.581
10	4	6	Very small
10	6	4	0
10	8	2	0
8	0	8	.868
6	0	6	.699
4	0	4	.540
2	0	2	.345

ACETIC ACID.

C. c. N acid per 50 c. c.	C. c. N alkali per 50 c. c.	Free Acid.	Velocity of Inversion.
10	0	10	1.000
10	2	8	.041
10	4	6	Very small
10	6	4	0
10	8	2	0
8	0	8	.945
6	0	6	.832
4	0	4	.592
2	0	2	.423

ON THE PROCESS OF MAKING CONSUMPTION SUGARS.—The manufacture of white or yellow grocery sugars for direct consumption is an industry which is of very small magnitude in these islands, but is one which is followed on a large scale elsewhere. The routine followed in Java has lately been described by Prinsen Geerligs.[9] Briefly the scheme there followed is:

"The method of working at present in vogue in Java is as follows: The mill juice is tempered in the cold with 15° Bé. milk-of-lime at the rate of 5 to 6 liters for every 1000 liters of the juice; then sulphur oven gases introduced until the reaction is just neutral, which point is determined by phenolphthalein paper. This neutralized juice is next passed through the juice-heaters, where it is heated to boiling point, then into the defecators. After separating the impurities by decantation the clear juice is conducted to the evaporators, whilst the subsided mud is sent through the filter-presses, and the resulting clear liquor united with that in the evaporators."

In Mauritius a somewhat similar procedure is followed with the additional use of phosphoric acid. The juice* was limed and sulphured cold, the resulting juice being very nearly neutral. After the usual process of settling had been gone through, phosphoric acid was added to the clarified juice in quantity up to 1% on the juice. The juice was now of a peculiar brownish olive green color and, using phenolphthalein as an indicator, possessed an acidity of about 1.5 cc. N acid per 100 cc. of juice. With such an acidity repeated tests failed to detect any inversion, i.e. such juices heated for 30 minutes in a bath of boiling water maintained their original polarization.

In Demerara a very similar process was followed, with the exception that the juices there had a considerably greater acidity which in my experience has reached as high as 3 cc. N acid per

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* That is to say, in certain factories with which the writer was once connected.

100 cc. of juices. These juices when looked at in a test tube of about ¼ inch diameter were almost colorless.

From what has already been written, it will be at once apparent that the degree of acidity allowable without inversion will depend not only on the free acid present, but also on the neutral salts. The amount of neutral salts will be connected with the quantity originally present and with the amount of lime, sulphur, and phosphoric acid used. Thus a juice heavily limed and neutralized with sulphurous acid will contain a maximum of neutral salt present as calcium sulphite. To such a juice a larger quantity of phosphoric acid can be added without inducing inversion than if less lime and sulphur had been originally used.[†]

To obtain data on this point, I conducted the following series of experiments with dilute acids at temperatures of from 97° C. to 98° C. The experiments were designed to determine the point at which inversion was inhibited entirely by the presence of neutral salts with varying amounts of free acid.

In the first series 2, 2.2, 2.4, etc., cc. of .2 N phosphoric acid was added to 25 cc. of a 20% solution of cane sugar, then followed by the addition of .2, .4, .6, etc., cc. of .2 N caustic soda. A series of such solutions was made up to 50 cc. and heated on the water bath for 30 minutes. After cooling they were polarized and the point at which inversion stopped was noticed. The results given below in tabular form show the point at which inversion was detectable with half an hour's heating at 97° C. to 98° C.

cc $\frac{N}{10}$ Phosphoric Acid in 100 cc.	cc. $\frac{N}{10}$ Soda in 100 cc.	Excess of free $\frac{N}{10}$ Acid in 100 cc.
12.8	4.8	8
25.6	9.6	16.0
38.4	14.4	26.0
48.0	16.0	32.0
62.0	22.0	40.0

Hence, depending on the amount of neutral salts, inversion may begin with an amount of free acid varying from 8 cc. $\frac{N}{10}$ to 40 cc. $\frac{N}{10}$ acid per 100 c.c., depending entirely upon the amount of neutral salt present.

EXPERIMENTS WITH JUICE.—I then made a series of experiments with cane juices to determine with what amount of acidity a juice could be worked without inversion occurring. A difference exists here between the experiment above detailed with acid and its neutral salt owing to the initial presence of neutral salts in cane juices. The cane juice itself was exactly neutral to azolitmin paper, and when heated for 30 minutes at 97° C. to 98° C. inversion became detectable in the presence of 6 cc. $\frac{N}{10}$ phosphoric acid per 100 cc. of juice.

[†] In my experience of white sugar manufacture, I have noticed that the beauty of the crystals seems to depend largely on the amount of free acid present in the juices. This is distinctly known to many sugar boilers who often have a practice of adding a very large quantity of lime to the juice followed by what in other cases would be a dangerous excess of sulphurous or phosphoric acid. Actually, they are thus working juices with a large amount of free acid in the presence of their neutral salts

In order to use quantities of salts and acids comparable with those used in practice, I calculated as follows: The amount of sulphur used in factories using sulphurous acid reaches up to a maximum of 5 lbs. per 1000 imperial gallons of juice. This is the largest quantity I have ever seen used. This quantity corresponds roughly to a concentration of .03 $\frac{N}{10}$ sulphur. The minimum quantity used is about one-third of this and would correspond to a concentration of .01 N. I accordingly limed a juice till it was just alkaline to phenolphthalein and added thereto sodium sulphite, so that the concentration was (a) .01 N, (b) .02 N, (c) .04 N. To these juices I then added 2, 4, 6, etc., cc. of $\frac{N}{10}$ phosphoric acid and determined at what concentration of phosphoric acid inversion was detectable with a heating of 30 minutes' duration at 97° C. to 98° C.

The results obtained were as below:

Concentration of Sodium Sulphite.	Inversion was Detectable with a Concentration of Phosphoric Acid cc. $\frac{N}{10}$ per 100 cc.
.01 N	24
.02 N	42
.04 N	68

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BULLETIN NO. 38

REPORT OF WORK
OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

The Effect of High Temperatures on Cane Sugar in Solution.

BY NOËL DEERR.

HONOLULU, HAWAII
1911

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AGRICULTURAL AND CHEMICAL SERIES — BULLETIN No. 36

REPORT OF WORK
OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

The Effect of High Temperatures on Cane Sugar in Solution.

BY NOËL DEERR.

HONOLULU, HAWAII
1911

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LETTER OF TRANSMITTAL.

To the Experiment Station Committee of the
Hawaiian Sugar Planters' Association,
Honolulu, Hawaii.

Dear Sirs:—I herewith submit for publication as Bulletin No. 36, of the Agricultural and Chemical Series, an article by Mr. Noël Deerr, Sugar Technologist, entitled: "The Effect of High Temperatures on Cane Sugar in Solution."

Yours very truly,

C. F. ECKART,
Director.

Honolulu, Hawaii, March 14, 1911.

THE EFFECT OF HIGH TEMPERATURES ON CANE SUGAR IN SOLUTION.

By Noël Deerr.

INTRODUCTION.

In a previous publication[1] from this Station the inversion of cane sugar, under the influence of acids and neutral salts, both at the ordinary laboratory temperature (circa 30° C.) and at the temperature of water boiling under atmospheric pressure, was discussed. The present publication gives a record of experiments designed to obtain information on the behavior of cane sugar at temperatures up to 135° C. in aqueous solution, in alkaline solution, and in aqueous solution in the presence of neutral salts. The connection between these experiments and the process of cane sugar manufacture comes under three heads.

a. *Steam Economy.*—With the possibility of using high pressure steam in the process of evaporation very sensible economies are to be obtained in the consumption of steam. The systems* most in favor in beet sugar factories are those known as the Pauly-Greiner pre-evaporation system, and the process known as the "Extra Steam," the former of which in later years has been very largely developed in preference to any system of evaporation—quintuple or sextuple effect. At the present time one hundred and ninety-one beet sugar factories in Germany employ the Pauly-Greiner system of pre-evaporation, and one hundred and three use the conventional quadruple evaporation.

The Pauly-Greiner system of pre-evaporation is not by any means a novelty, since it was developed and put into actual use during the years 1885 to 1887. The system of using "extra steam" antedates the pre-evaporation system by several years. Its inception is due to Rillieux, and it has been developed chiefly by Rassmus and Lexa on the continent of Europe. The cane sugar factories that have adopted either of these schemes are very few; and it may be said that these schemes are generally ignored in cane sugar practice. Before, however, any such scheme could be advised, it is necessary to examine the behavior of cane sugar products at high temperatures under conditions representative of those occurring in practice.

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* For a description of the rationale of these systems of evaporation reference may be made to Ware, "Beet Sugar Manufacture and Refining," Vol. II, page 129; to Deerr, "Cane Sugar,' page 136; to Abraham, "Die Dampfwirtschaft in der Zuckerfabrik"; and best of all to Stammer, "Der Dampf in der Zuckerfabrik," Vol. II, page 117.

b. *Asepsis.*—It has been established both for the beet and cane sugar industry that the conventional system of evaporation with the highest temperatures not above 100° C. is not sufficient to destroy the micro-organisms that enter with the juice and which are introduced into the process of manufacture whenever low sugars obtained from massecuites stored over long periods are remelted or taken into the pans as "seed." It is easy to see that the presence of micro-organisms from these two sources is beyond complete control. although attention to cleanliness may notably restrict the number introduced. Admitting the unavoidability of their presence in some degree, it becomes a matter of interest to determine if a temperature sufficiently elevated to obtain their destruction can be attained without loss of sugar.

c. *Clarification.*—It is customary in some factories to heat the juice up to 115° C. to 120° C. in closed tubular heaters with the object of obtaining a superior "clarification" including in this term such points as rapidity of settling, ease of filtration, brightness of juice.

PREVIOUS WORK.—Up to quite recently the only detailed study of the effect of higher temperatures on cane sugar in solution is that due to Herzfeld[2]. In his experiments cane sugar solutions of concentration varying from 10% to 50% were heated at temperatures up to 140° C. The containing vessels were of metal* and the solutions were made alkaline to the extent of .01% to .05%. The results of Herzfeld's experiments are given below in Table I, which shows the percentage of sugar destroyed in one hour under the specified conditions.

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* It was observed in this series of experiments that in neutral solution inversion of cane sugar proceeded much more rapidly in metal than in glass vessels. The phenomenon is usually attributed to a catalytic action, obtaining with metal, and not with glass vessels. A simpler explanation would attribute the difference in behavior to small quantities of alkali dissolved out from the glass containers.

TABLE I.

Decomposition of cane sugar in metal containers in very **dilute alkaline solution: figures give percentage of cane sugar destroyed in one hour's heating at the specified temperature. (Herzfeld).**

°C.	10%	15%	20%	25%	30%	35%	40%	45%	50%
80	0.0444	0.0373	0.0301	0.0229	0.0157	0.0168	0.0179	0.0190	0.0200
90	0.0790	0.0667	0.0541	0.0418	0.0290	0.0317	0.0344	0.0371	0.0392
100	0.1140	0.0961	0.0781	0.0602	0.0423	0.0466	0.0508	0.0551	0.0584
110	0.1630	0.1362	0.1093	0.0825	0.0557	0.0612	0.0667	0.0721	0.0766
120	0.2823	0.2582	0.2341	0.2098	0.1857	0.2063	0.2669	0.2474	0.2678
130	2.0553	1.7582	1.4610	1.1638	0.8667	0.9451	1.0235	1.0119	1.1800
140	5.1000	.....	.....	......	.....	.....	.....	.....	.....

Very recently, two studies, covering some of the same ground as is gone over in the present publication, have appeared. Zujew[3] working with factory (beet) juices has arrived at the conclusion that in the first effect of an evaporator no loss of sugar need be feared provided the temperature does not rise above 134° C.

Douschsky[4] has extended the experiments of Herzfeld up to concentration of 75%, using however glass instead of metal vessels, and as in Herzfeld's experiments, making the solutions slightly alkaline. The results of his experiments in so far as they are a continuation of Herzfeld's are given below:

TABLE II.

Decomposition of cane sugar in glass containers in very dilute alkaline solution: figures give the percentage of cane sugar destroyed in one hour's heating at the specified temperature. (Douschsky).

Temperature °C.	50%	55%	60%	65%	70%	75%
80	0.0260	0.0260	0.0230	0.0200	0.0170	0.0170
90	0.0260	0.0490	0.0350	0.0280	0.0170	0.0350
100	0.0510	0.0710	0.0350	0.0350	0.0350	0.0510
105	0.0752	0.0752	0.0878	0.0878	0.0752	0.0752
110	0.0878	0.1003	0.1003	0.1003	0.0878	0.1003
115	0.1504	0.1837	0.1337	0.1837	0.1837	0.1672
120	0.3009	0.3009	0.2508	0.2508	0.2257	0.2006
125	0.7021	0.6519	0.7021	0.6018	0.6018	0.7021
130	1.3039	1.2537	1.3039	1.2036	1.1033	1.0531
135	2.1063	1.9057	1.7051	1.6549	1.8556	1.7051

As these experiments deal only with the effect of high temperatures on sugar in very dilute alkaline solution, it was thought advisable to study the action in the presence of varying quantities of alkalies or neutral salts typical of those naturally occurring in cane juices.

EXPERIMENTAL DETAILS.—The routine followed in the experiments, the results of which are given below, was as under:

Fifty cubic centimeters of a 40%—by volume—sugar solution were placed in a 100 cc. sugar flask; to this was added in solution the alkali or salt, the action of which was to be studied. A quantity of water was then added so as to bring the contents of the flask to a certain definite volume. A batch of flasks so prepared was then placed in an autoclave of the pattern used in bacteriological laboratories for the purposes of sterilization under pressure. The fittings of the autoclave comprised a thermometer and sensitive adjustable pop valve whereby a constant pressure and temperature* could be obtained. After half an hour's heating at the desired temperature, the autoclave and its contents were allowed to cool, the flasks removed, made up to 100 cc., and their contents polarized.

It was observed early in these experiments that reasonable duplicates were hard to obtain. This source of error is to be attributed to the different amounts of alkali dissolved from the flask. All the flasks were digested with hydrochloric acid for five hours when it was found that the difference in duplicate experiments tended to disappear. In addition, certain flasks which gave irregular results were taken out and not further used. Although exact duplicates could not be obtained, eventually reasonably small differences in duplicate experiments were found.

As examples of the differences which occurred in duplicate experiments and which can only be attributed to the influence of the containers, the following figures are given:

Temperature.	110° C.	115° C.	120° C.	125° C.	130° C.	135° C.
Original polarization....	78.0	78.0	78.0	78.0	78.0	78.0
Polarization after heating for 30 minutes at the specified temperature....	78.0	77.3	76.5	73.7	65.2	38.3
	...	...	76.2	73.0	63.0	32.1
	78.0	77.3	76.5	73.7	61.2	35.3

ACTION OF HIGH TEMPERATURES ON CANE SUGAR SOLUTIONS IN THE PRESENCE OF VARYING QUANTITIES OF ALKALIES.

In this experiment 50 cc. of a 40% by volume solution of cane sugar were placed in a 100 cc. flask. To this was added the quantities shown of $\frac{N}{25}$ caustic soda solution, a maximum of 30 cc. being employed. The solutions were in all cases made up to a volume of 80 cc. They were then heated for half an hour at the temperature specified in the annexed table. After cooling and making up to 100 cc. the solutions were polarized. In Table III are entered the readings† on the Ventzke scale so obtained, i. e. the scale in which 26.015 grams sugar in 100 true cc. read at 20° C. gives a reading of 100°. On examining the results contained in Table III, the following conclusions can be drawn:

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* The adjustment of the valve to obtain a fixed pressure was fairly easy. In the experiments detailed below a temperature of 125° C., etc., should read the temperature varied from 124° C. to 126° C. for not more than five minutes, and was steady at 125° for at least twenty-five minutes.

† The rational way of expressing the experimental results described in this publication would be to calculate from the polarization the rate of inversion; owing, however, to the various sources of error mentioned above, I have not made this calculation.

TABLE III.

Action of high temperatures on cane sugar in the presence of varying quantities of caustic soda; total volume of solution 80 c. c.; time of heating thirty minutes; polariscope reading taken in 100 c. c.

C. C. of $\frac{N}{25}$ Caustic Soda	Temperature and Pressure above Atmosphere. Lbs. per sq. in.							
	100° C. 212° F. 0.0	105° C. 221° F. 2.8	110° C. 230° F. 6.1	115° C. 239° F. 9.8	120° C. 248° F. 14.1	125° C. 257° F. 19.0	130° C. 266° F. 24.5	135° C. 275° F. 30.7
Original Polarization	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0
0.0	Polarization did not change.	Polarization did not change.	Polarization did not change.	77.3	76.5	73.7	61.2	35.3
0.5				77.5	76.9	74.7	68.0	39.3
1.0				77.5	77.2	75.5	70.4	46.1
1.5				77.6	77.2	75.8	72.3	55.3
2.0				77.5	77.5	76.3	73.1	57.1
2.5				77.7	77.4	76.3	74.0	59.0
3.0				77.8	77.7	77.0	74.2	62.6
3.5				77.8	77.7	77.4	74.8	65.4
4.0				Polarization constant.	77.8	77.6	75.0	67.0
5.0					77.7	77.7	75.5	70.7
6.0					Polarization constant.	77.7	76.3	72.4
7.0						Polarization constant.	76.3	73.1
8.0							76.4	73.7
9.0							76.5	72.0
10.0							76.6	73.0
12.5							76.5	74.0
15.0							Polarization constant.	74.5
17.5								75.0
20.0								75.0
22.5								75.1
25.0								75.1
27.5								75.0
30.0								75.1

1. With a heating extending up to 30 minutes in neutral solution (i. e. neutral with the exception of alkali dissolved from the glass containers) inversion of cane sugar is not detectable under a temperature of 110° C.
2. The inversion increases with rise of temperature and above 125° C. the increase is very rapid.
3. The inversion at all temperatures is very largely inhibited by very small quantities of alkalies.
4. At temperatures above 110° C. the presence of increasing quantities of alkalies progressively retards the inversion up to a certain limit, beyond which a further increase in the amount of alkali present has no effect on the amount of sugar inverted, but the polarizations remain constant.

It was observed that with the larger quantities of alkali and especially at the higher temperatures that the solutions became very dark. This darkening of the solution was not attended by a greater destruction of sugar; and indeed, up to the limit where constant polarizations were obtained, it might be said that the destruction of sugar was inversely as the darkening. This observation is of some little interest, since it is often taken for granted in cane sugar manufacture that a darkening of the juice is an indication of some avoidable loss.

In the extreme cases the solutions were too dark to be observed in the polariscope directly. The color was in great part discharged on neutralization of the alkali by any acid, and the readings tabulated were thus obtained after neutralization with acetic acid.

ACTION OF NEUTRAL SALTS ON THE INVERSION OF CANE SUGAR AT TEMPERATURES ABOVE 100° C.

In Bulletin 35 of this series, the action of the halides, nitrates, sulphates, and several organic salts of the alkalies in combination with acids on the inversion of cane sugar was examined. It was then shown that the halides and nitrates of the alkalies and alkaline earths accelerated the invertive action of acids when present in more concentrated solution in the cold, but no accelerative action was detected when in dilute solution at 100° C. All the other salts of the alkalies and alkaline earths examined were found under all conditions to possess a retarding action.

In the experiments the results of which are given in Table IV, 50 cc. of a 40% solution of cane sugar, were placed together with 10 cc. of a 3 N solution of the salt in 100 cc. flasks and were heated in an autoclave for 30 minutes. The concentration of the salt was then .5 N. The figures entered up give the degrees Ventzke of the solutions after heating and making up to 100 cc. when observed in a 20 cm. tube.

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8. *J*
9. *D*

On examining the results, the following conclusions can be drawn:

1. At temperatures of 105° C. and upwards the chlorides, bromides, iodides, nitrates, and sulphates of the alkalies and alkaline earths in .5 N solution cause an inversion of cane sugar much greater than that observed in pure aqueous solution.
2. There is little difference between the action of the chlorides, bromides, and iodides of lithium, sodium, and potassium, and, owing to the varying effect of small quantities of alkalies dissolved from the glass containers, it is impossible to say whether their action is identical or not, though the action of the lithium salts is apparently greater than that of the sodium and potassium salts; however, the action of the bromides and iodides is certainly not greater than that of the chlorides.
3. The action of the nitrates of lithium, sodium, and potassium is very similar to that of the halides of the same metals; and again, the action of the lithium salt is apparently greater.
4. The action of the chlorides and nitrates of the alkaline earths is much greater than is the action of the corresponding salts of the alkalies.
5. Of the salts of the alkaline earths, those of magnesium are much more energetic in action than are those of calcium, strontium, and barium. Between the last three no difference in action is apparent.
6. The sulphates of the alkalies show no appreciable difference in their action as between themselves, though their action is much weaker than is the action of the corresponding halides.
7. The action of magnesium sulphate is very pronounced and is of the same order as that of the chlorides of the alkalies.

The results obtained and described above show several points of dissimilarity from those obtained when studying the accelerative action of neutral salts on the rate of inversion cane sugar by acids. It was then found:

1. That the sulphates of the alkalies and alkaline earths retarded the rate of inversion at temperatures up to 100° C. At more elevated temperatures they cause inversion in the absence of acids. This observation brings the behavior of these salts into line with the behavior of ammonium sulphate which at ordinary temperatures retards the rate of inversion and causes inversion at a temperature of 100° C.
2. It was found previously that the accelerative action of the salts of the alkalies and alkaline earths on the rate of inversion of cane sugar by acids was substantially the same.
3. It was found previously that the accelerative action of the halide salts of the alkalies and alkaline earths increased from chloride to bromide, and from bromide to iodide.

TABLE IV.

Action of high temperatures on cane sugar in the presence of .5 N neutral salts: total volume of solution 60 c. c.; **time of heating thirty minutes; polariscope reading taken in 100 c. c.**

	Temperature and Pressure above Atmosphere. Lbs. per sq. in.							
	100° C. 212° F. 0.0	105° C. 221° F. 2.8	110° C. 230° F. 6.1	115° C. 239° F. 9.8	120° C. 248° F. 14.1	125° C. 257° F. 19.0	130° C. 266° F. 24.5	135° C. 275° F. 30.7
Original polarization.....	No change in Polarization	78.0	78.0	78.0	78.0	78.0	78.0	78.0
No salt.................		78.0	78.0	77.3	76.5	73.7	65.2	38.3
Lithium Chloride		77.7	77.0	76.0	71.8	61.2	32.2	—11.8
Sodium "		77.4	76.6	74.0	71.9	64.0	37.4	—13.0
Potassium "		77.7	76.7	76.0	72.8	65.7	38.1	—14.3
Magnesium "		76.5	75.5	71.0	50.3	7.8	—19.2	—19.2
Calcium "		77.1	76.0	74.0	67.2	31.6	—12.2	—19.2
Strontium "		...	75.8	73.3	64.1	32.0	—11.1	—19.2
Barium "		77.0	76.0	72.1	58.2	33.4	— 8.9	—19.2
Lithium Nitrate		...	...	...	71.3	61.8	20.2	—15.5
Sodium "		77.6	77.0	76.7	73.0	64.6	36.7	—11.4
Potassium "		77.7	77.1	75.3	73.4	65.8	48.0	—14.4
Magnesium "		76.7	75.8	73.6	64.1	23.5	—14.0	—19.4
Calcium "		76.8	76.0	74.0	68.2	34.1	— 8.0	—19.4
Strontium "		77.0	75.9	74.5	67.0	38.0	—10.0	—19.2
Barium "		...	...	74.0	69.2	35.0	— 8.4	—19.4
Lithium Bromide		77.5	77.0	76.3	73.6	62.8	38.7	—18.0
Sodium "		77.5	76.5	75.8	73.3	68.0	40.0	—15.7
Potassium "		77.6	76.6	76.2	73.8	67.8	45.0	— 9.9
Sodium Iodide		77.5	76.3	75.5	72.5	66.1	45.4	—12.2
Potassium "		77.7	76.8	76.0	75.0	69.1	48.3	— 6.6
Lithium Sulphate		...	...	...	74.5	72.0	61.3	27.7
Sodium "		77.9	77.3	76.0	75.3	71.0	57.0	28.6
Potassium "		77.9	77.2	76.4	75.0	70.0	61.0	24.8
Magnesium "		77.3	76.1	75.0	70.0	62.0	31.4	—13.7

On examining the results, the following conclusions can be drawn:

1. At temperatures of 105° C. and upwards the chlorides, bromides, iodides, nitrates, and sulphates of the alkalies and alkaline earths in .5 N solution cause an inversion of cane sugar much greater than that observed in pure aqueous solution.
2. There is little difference between the action of the chlorides, bromides, and iodides of lithium, sodium, and potassium, and, owing to the varying effect of small quantities of alkalies dissolved from the glass containers, it is impossible to say whether their action is identical or not, though the action of the lithium salts is apparently greater than that of the sodium and potassium salts; however, the action of the bromides and iodides is certainly not greater than that of the chlorides.
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5. Of the salts of the alkaline earths, those of magnesium are much more energetic in action than are those of calcium, strontium, and barium. Between the last three no difference in action is apparent.
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1. That the sulphates of the alkalies and alkaline earths retarded the rate of inversion at temperatures up to 100° C. At more elevated temperatures they cause inversion in the absence of acids. This observation brings the behavior of these salts into line with the behavior of ammonium sulphate which at ordinary temperatures retards the rate of inversion and causes inversion at a temperature of 100° C.
2. It was found previously that the accelerative action of the salts of the alkalies and alkaline earths on the rate of inversion of cane sugar by acids was substantially the same.
3. It was found previously that the accelerative action of the halide salts of the alkalies and alkaline earths increased from chloride to bromide, and from bromide to iodide.

TABLE V.

Action of high temperatures on cane sugar in the presence of .42 N neutral salts and varying quantities of caustic soda; total volume of solution 70 c. c.; time of heating thirty minutes; polariscope reading taken in 100 c. c.

C. C. of $\frac{N}{5}$ Caustic Soda	Temperature and Pressure above Atmosphere. Lbs. per sq. in.								
	125° C. 257° F. 19.0	130° C. 266° F. 24.5	135° C. 275° F. 30.7	125° C. 257° F. 19.0	130° C. 266° F. 24.5	135° C. 275° F. 30.7	125° C. 257° F. 19.0	130° C. 266° F. 24.5	135° C. 275° F. 30.7
	Calcium Chloride			Potassium Nitrate			Sodium Sulphate		
Original Polarization	75.1	75.1	75.1	75.1	75.1	75.1	75.1	75.1	75.1
No Salts or Alkali	70.8	62.4	35.3	70.8	62.4	35.3	70.8	62.4	35.3
0.0	33.6	—10.0	—18.8	64.3	45.0	—14.0	68.1	56.0	25.8
0.5	56.2	1.1	—16.2	71.8	51.3	— 4.1	72.0	66.4	40.1
1.0	64.2	14.0	—10.0	72.8	67.2	37.8	73.5	68.8	52.8
1.5	70.1	24.0	0.0	73.3	70.1	44.1	73.8	70.3	53.5
2.0	71.8	54.2	12.0	73.7	72.2	53.4	74.2	71.7	58.0
2.5	72.6	58.7	28.2	74.1	72.4	59.7	74.3	72.4	60.1
3.0	73.3	62.8	40.0	74.3	72.8	65.3	74.3	74.0	63.1
4.0	73.8	66.4	49.0	74.3	74.0	68.7	74.2	74.0	68.4
5.0	74.2	72.4	64.7	74.3	74.1	70.5	74.3	73.9	72.1
6.0	74.2	73.4	67.5	74.2	74.0	72.2	74.2	74.0	73.5
7.0	74.2	74.0	71.7	74.2	74.1	73.2	74.3	73.9	73.5
8.0	74.1	74.0	72.0	74.3	74.1	73.4	74.2	73.9	73.4
9.0	74.2	74.0	72.8	74.3	74.0	73.3	74.3	74.0	73.5
10.0	74.2	74.0	72.8	74.2	74.1	73.3	74.1	73.9	73.4

ACTION OF NEUTRAL SALTS AND ALKALIES ON THE INVERSION OF CANE SUGAR AT ELEVATED TEMPERATURES.

Since in cane juices the neutral salts occur in the presence of greater or smaller quantities of free lime, it is of interest to examine the action of neutral salts in the presence of small quantities of free alkali. The experiments were made precisely as described in the preceding paragraphs. The three salts selected were: calcium chloride, potassium nitrate and sodium sulphate. To 50 cc. of a sugar solution were added 10 cc. of 3 N salt solution and the quantity of $\frac{N}{5}$ caustic soda shown in Table V, so much water was also added, that the volume of the contents of each flask was 70 cc. Examination of the results detailed in the above table show:

1. That the invertive action of neutral salts at elevated temperatures is modified by small quantities of alkalies.

2. With the addition of a certain quantity of alkali, a minimum quantity of sugar is inverted; and increasing the quantity of alkali beyond this point does not further decrease the amount of sugar inverted.

3. In the presence of neutral salts the amount of alkali necessary to obtain the minimum loss of sugar is greater than in their absence; thus, while at a temperature of 135° C. the point of minimum inversion of sugar first occurs when 17.5 cc. $\frac{N}{25}$ alkali are present in 70 cc., i. e. a concentration of alkali of .00875 N, in the presence of 10 cc. 3 N calcium chloride in 70 cc. or a concentration of .43 N, the point of minimum inversion occurs when 9 cc. $\frac{N}{5}$ alkali are present, i. e. at a concentration .026 N.

ACTION OF THE SALTS OF WEAKER ACIDS ON THE INVERSION OF SUGAR AT ELEVATED TEMPERATURES.

The salts selected for examination as typical of the action of such salts as may occur in cane juices were sodium acetate, sodium potassium tartrate, and potassium oxalate. The method of experiment followed was precisely as used before; the salts were added in $\frac{N}{5}$ concentration, and the volume of the mixed salt and sugar solution was 80 cc.

TABLE VI.

Action of high temperatures on cane sugar in the presence of neutral salts of weaker acids: total volume of solution 80 c. c.; time of heating thirty minutes; polariscope reading taken in 100 c. c.

C. C. of $\frac{N}{5}$ Salt.	Temperature and Pressure above Atmosphere. Lbs. per sq. in.											
	120° C. 248° F. 14.1	125° C. 257° F. 19.0	130° C. 266° F. 24.5	135° C. 275° F. 30.7	120° C. 248° F. 14.1	125° C. 157° F. 19.0	130° C. 266° F. 24.5	135° C. 275° F. 30.7	120° C. 248° F. 14.1	125° C. 257° F. 19.0	130° C. 266° F. 24.5	135° C. 275° F. 30.7
	Sodium Acetate				Potassium Sodium Tartrate				Potassium Oxalate			
Original Polarization	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0
0.0	76.2	73.0	63.0	32.1	76.2	73.0	63.0	32.1	76.2	73.0	63.0	32.1
.25	76.4	74.1	70.6	58.4	76.3	73.8	70.0	47.3	76.4	73.3	69.8	44.3
.5	76.8	74.7	71.2	61.8	76.7	74.0	70.8	53.0	76.4	73.8	70.4	48.0
1.0	77.0	75.0	73.8	67.0	76.7	74.2	73.0	62.0	76.5	73.9	72.9	70.0
2.0	77.1	75.0	74.5	70.0	76.8	74.6	73.6	65.2	76.7	74.2	73.4	63.1
3.0	77.2	75.2	75.0	70.8	76.8	74.6	74.1	66.1	76.7	74.3	74.0	64.4
5.0	77.2	75.4	75.2	72.1	77.0	74.8	74.4	68.2	76.8	74.5	74.1	67.5
7.5	77.2	75.7	75.5	72.4	77.0	75.2	74.6	68.6	76.8	74.8	74.3	67.7
10.0	...	75.9	75.6	72.8	77.0	75.4	74.7	69.2	76.8	75.0	74.4	68.2
12.5	...	75.9	75.8	73.0	...	75.5	74.8	70.0	...	75.2	74.4	69.4
15.0	...	75.8	76.1	73.6	...	75.4	75.0	70.8	...	75.2	74.6	70.2
20.0	...	75.9	76.2	74.3	...	75.5	75.1	71.7	...	75.2	74.6	70.7
22.5	...	...	76.4	74.7	...	...	75.2	71.9	...	...	74.7	70.9
25.0	...	...	76.4	74.7	...	...	75.4	71.8	...	...	74.8	71.3
27.5	...	...	76.4	74.6	...	...	75.4	71.9	...	...	74.8	71.3
30.0	...	...	76.4	74.7	...	...	75.4	71.9	...	...	74.8	71.3

From the results tabulated in Table VI it follows:

1. That the salts of weaker acids retard the inversion of cane sugar at high temperatures.
2. The retardation decreases progressively from acetate to tartrate to oxalate.
3. The action is in all respects comparable to that of free alkali, a point of minimum inversion occurring beyond which the addition of further quantities of salt does not decrease the inversion.
4. The minimum inversion in the presence of the salts of weak acids is greater than it is in the presence of alkalies and much larger quantities of salts are required to obtain a minimum inversion than of alkalies.

Action of Phosphates and Sulphites of the Alkalies.

By reason of the somewhat extended use of phosphoric and sulphurous acids in the process of sugar manufacture, it was of interest to examine the action of their alkaline salts on the inversion of cane sugar at elevated temperatures. The experiment was carried out at one temperature only, 130° C., with the results shown in Table VII.

TABLE VII.

Action of certain salts at 130° C. on the inversion of cane sugar. Total volume of solution 80 c. c.; time of heating thirty minutes; polariscope reading taken in 100 c. c.

C. C. N. Salt.	Sodium Sulphite.	Mon-Acid Potassium Phosphate.	Di-Acid Potassium Phosphate.
Original polarization	80.5	80.5	80.5
0	59.3	59.3	59.3
1	60.6	74.2	58.5
2	62.3	77.8	60.6
3	65.6	78.5	60.7
4	71.8	79.2	60.6
6	72.8	79.8	57.4
10	74.8	79.8	60.6
20	79.4	79.8	58.4
30	79.4	...	62.0

From these results the following conclusions may be drawn:

1. Normal sulphites and mon-acid phosphates of the alkalies retard the rate of inversion of cane sugar at high temperatures.
2. Bi-acid phosphates of the alkalies are without action on the rate of inversion.

COMPARISON OF THE ACTUAL VELOCITIES OF REACTION.

The difficulties whereby sources of error were introduced into these experiments have already been explained and therefore I have not calculated out the velocity of inversion, but have expressed the results in terms of a fall in polarization. There was, however, strong evidence of certain regularities holding. I therefore have calculated the mean fall in polarization at the temperatures 125° C. and 130° C. of the chlorides and nitrates of metals in the first periodic family and of those in the second (leaving out of consideration the magnesium salts which evidently behaved differently to the other salts of this family), and also of the sulphates of the salts in the first periodic family, and also of magnesium sulphate. The results are given in Table VIII where $M'Cl$ denotes the average results obtained with lithium, sodium, and potassium chlorides; $M''Cl_2$, the average results obtained with calcium, strontium, and barium chlorides respectively. In the column headed "polarization" is given the average polarization after heating to the specified temperature under the already stated conditions of experiment. The total change in polarization on complete inversion was 100.0, whence are calculated the values of $log \frac{a}{a-x}$ where a is the total change in polarization on complete inversion, and x is the fall in polarization.

TABLE VIII.

Velocity of inversion of cane sugar at 125° C. and at 130° C. under the influence of certain neutral salts. Initial polarization 78° Ventzke; polarization on complete inversion—22° Ventzke.

Salts.		Polarization.	Log $\frac{a}{a-x}$	Log $\frac{a}{a-x}$ corrected for Velocity in Aqueous Solutions.
0	125	73.7	.0192	....
0	130	65.2	.0596	....
M' Cl.	125	63.6	.0674	.0482
M' Cl.	130	25.9	.2373	.1777
M'' Cl_2	125	32.7	.2622	.2430
M'' Cl_2	130	—10.7	.9077	.8481
M' NO_3	125	64.0	.0656	.0464
M' NO_3	130	35.0	.2440	.1845
M'' $(NO_3)_2$	125	35.7	.2390	.2198
M'' $(NO_3)_2$	130	— 8.8	.8794	.8199
M'_2 SO_4	125	71.0	.0315	.0123
M'_2 SO_4	130	59.8	.0871	.0276
Mg SO_4	125	62.0	.0755	.0563
Mg SO_4	130	31.4	.2721	.2125

In comparing these values allowance must be made for the inversion due to heating in the presence of water only. I have accordingly calculated the velocity of inversion for water only and have deducted this value from the rate of inversion found in the presence of the various salts. The values of the rate of inversion due to the salts alone is given in the last column of Table VIII.

After having obtained these values, I then proceeded to compare the ratios of the velocities of inversion of the different groups of salts. The results of the comparisons are shown in tabular form in Table IX, where an expression, such as M′ Cl 125, denotes the velocity of inversion at 125° C. of the chlorides of the metals of the first periodic family, etc. Examination of these results leads to the following conclusions:

TABLE IX.

Comparison of velocities of inversion of cane sugar at 125° C. and at 130° C. under the influence of certain neutral salts.

$$\frac{\mathrm{M'\ Cl}\quad 130}{\mathrm{M'\ Cl}\quad 125} = \frac{.1777}{.0482} = 3.69$$

$$\frac{\mathrm{M''\ Cl_2}\quad 130}{\mathrm{M''\ Cl_2}\quad 125} = \frac{.8481}{.2430} = 3.48$$

$$\frac{\mathrm{M'\ NO_3}\quad 130}{\mathrm{M'\ NO_3}\quad 125} = \frac{.1845}{.0464} = 3.97$$

$$\frac{\mathrm{M''\ (NO_3)_2}\quad 130}{\mathrm{M''\ (NO_3)_2}\quad 125} = \frac{.8199}{.2198} = 3.68$$

$$\frac{\mathrm{M'_2\ SO_4}\quad 130}{\mathrm{M'_2\ SO_4}\quad 125} = \frac{.0276}{.0123} = 2.24$$

$$\frac{\mathrm{Mg\ SO_4}\quad 130}{\mathrm{Mg\ SO_4}\quad 125} = \frac{.2125}{.0563} = 3.79$$

$$\frac{\mathrm{M''\ Cl_2}\quad 130}{\mathrm{M'\ Cl}\quad 130} = \frac{.8481}{.1777} = 4.76$$

$$\frac{\mathrm{M''\ Cl_2}\quad 125}{\mathrm{M'\ Cl}\quad 125} = \frac{.2430}{.0482} = 5.07$$

$$\frac{\text{M}''\ (\text{NO}_3)_2\ 130}{\text{M}'\ (\text{NO}_3)_2\ 130} = \frac{.8193}{.1845} = 4.44$$

$$\frac{\text{M}''\ (\text{NO}_3)_2\ 125}{\text{M}'\ (\text{NO}_3)_2\ 125} = \frac{.2198}{.0464} = 4.75$$

$$\frac{\text{Mg SO}_4\ \ 125}{\text{M}'_2\ \text{SO}_4\ \ 125} = \frac{.0563}{.0123} = 4.57$$

$$\frac{\text{Mg SO}_4\ \ 130}{\text{M}'_2\ \text{SO}_4\ \ 130} = \frac{.2125}{.0276} = 7.70$$

1. The velocity of inversion due to neutral salts of the alkalies and alkaline earths is greater at 130° C. than at 125° C. in proportion from 3.5 to 4.0 times as great and this ratio is independent of the salt.

2. The velocity of inversion of the salts of the alkaline earths (excluding magnesium) is about five times as great as is the velocity of inversion of the same salts of the alkalies (lithium, sodium, potassium), and this ratio holds for the temperatures 125° C. and 130° C.

The figures obtained when comparing the effect of magnesium sulphate with that due to the sulphates of the alkalies are irregular, and this is perhaps due to the large percentage error introduced due to the small velocity of inversion of the sulphates of the alkalies.

THE EFFECT OF VARYING QUANTITIES OF NEUTRAL SALTS.

This was studied only in so far as regards the action of calcium chloride at 120° C.; 50 cc. of a 40% sugar solution was made up in all to 70 cc. containing from 0 to 20 cc. of a 3 N solution of calcium chloride. The results obtained are as given in Table X. In this case I have calculated out the velocity of inversion. This is given in the last two columns of Table X; in the penultimate column are given values of $log \frac{a}{a-x}$ where a is the total change on complete inversion and x is the fall in polarization; in the last column are given the values of the rates of inversion referred to equal concentration of salt, i. e. divided by the number of cubic centimeters of salt solution added. It will be seen that with larger quantities of salt solution, the velocity of reaction tends to become directly proportional to the amount of salt present. With the less quantities of salt added the accuracy of the experimental result is vitiated by the varying amounts of alkali dissolved from the glass containers and also by small errors of observation having a proportionately larger influence.

TABLE X.

Action of varying amounts of calcium chloride on the inversion of cane sugar at 120° C.; time of heating, thirty minutes; volume of solution 70 c. c.; polariscope reading taken in 100 c. c.

C. C. 3N Salt Solution.		Log $\frac{a}{a - x}$	
Original polarization	79.3	.....	.....
0	78.5	.00217	.....
2	76.1	.01403	.00521
4	72.0	.03256	.00814
6	69.9	.04239	.00706
8	69.3	.04528	.00566
10	68.0	.05179	.00518
12	67.4	.05448	.00454
14	66.3	.06052	.00433
16	65.3	.06554	.00409
18	63.7	.07294	.00404
20	62.1	.08099	.00405

EFFECT OF DURATION OF HEATING.

In all the experiments previously detailed, a constant period of heating of 30 minutes was adopted. No special significance attaches to this period; it was adopted as a convenient period which could be measured with smaller error, a one which allowed reasonably large differences in polarization to be obtained and as a period representative of the maximum time over which factory products would under any condition be exposed to the action of elevated temperatures. To study the effect of time, the action of magnesium chloride in $\frac{N}{2}$ concentration on a 40% sugar solution was studied at a temperature of 125° C. The experiment was made as already described. The results obtained are given in Table XI, the velocity of inversion given in the last column is referred to minutes and common logarithms.

TABLE XI.

Time.	Polarization.	$\frac{1}{t} \log \frac{a}{a-x}$
0 Minutes	81.2	.....
5 "	75.5	.00487
10 "	65.6	.00714
20 "	40.3	.01071
25 "	15.8	.01722
30 "	—10.2	.03058

It will be seen that apparently at any rate Wilhelmy's law of mass action does not apply here, the value of the constant increasing regularly with time of heating.

This observation is of considerable importance in considering the bearing of the results obtained dealing with the inversion of sugar at elevated temperatures on the effect in the factory; for evidently if with half an hour's heating under certain conditions a loss of 3% of sugar occurred, then in five minutes (treating the active mass of the sugar as unchanged) the loss would be $3 \times \frac{5}{30} \times \frac{.00487}{.03058} = .08\%$.

THE CONNECTION BETWEEN TEMPERATURE AND RATE OF INVERSION.

The equation connecting temperature and velocity of inversion under the influence of acids, following on the work of Urech and Spohr[5] is of the form

$$C_1 = C_0 e^{-\frac{A(T_1 - T_0)}{T_1 T_0}}$$

where C_1 and C_0 are the rates of inversion at T_1 and T_0; e is the base of the natural system of logarithms; and A is a constant.

In order to test the occurrence of a similar equation when cane sugar is inverted under the influence of neutral salts or in aqueous solution, I calculated the average fall in polarization for salts of the formula M Cl, $M_2'SO_4$, for magnesium sulphate and also of sugar in aqueous solution.

With these data, I then calculated values of $\log \frac{a}{a-x}$ where a is the total change in polarization on complete inversion; and x is the fall in polarization. The results of the calculations are given in Tables XII, XIII, XIV and XV.

TABLE XII.

Rate of inversion of cane sugar in aqueous solution at different temperatures. Initial polarization 78.0° Ventzke; polarization after complete inversion—22.0° Ventzke.

Temperature °C.	Polarization after 30 minutes.	Fall in Polarization = x	$\text{Log} \dfrac{a}{a - x}$	$\dfrac{\text{Velocity at 135° C.}}{\text{Velocity at the specified temperature.}}$
100	78.0	0	....	....
105	78.0	0	....	....
110	78.0	0	....	....
115	77.3	.7	.0030	73.27
120	76.5	1.5	.0065	33.66
125	73.7	4.3	.0190	11.57
130	65.2	12.8	.0596	3.69
135	38.3	39.7	.2198	1.00

TABLE XIII.

Rate of inversion of cane sugar in the presence of $\frac{N}{2}$ salts of the Alkaline Chlorides: Initial polarization 78.0 Ventzke. Polarization after complete inversion —22° Ventzke.

Temperature °C.	Polarization after heating.	Fall in Polarization = x	Log $\frac{a}{a - x}$	Log $\frac{a}{a - x}$ for water.	Difference of Cols. 4 & 5	Velocity at 135° C. / Velocity at the specified temperature.
105	77.6	.4	.00177	....	.0018	466.6
110	76.7	1.3	.00570	....	.0057	144.9
115	75.3	2.7	.01187	.0030	.0088	93.4
120	72.1	5.9	.02638	.0065	.0198	41.6
125	63.6	14.4	.06765	.0190	.0485	17.0
130	35.9	42.1	.2373	.0596	.1777	4.7
135	—13.0	91.0	1.0457	.2198	.8259	1.00

TABLE XIV.

Rate of inversion of cane sugar in the presence of $\frac{N}{2}$ salts of the Alkaline Sulphates: Initial polarization 78.0 Ventzke. Polarization after complete inversion —22° Ventzke.

Temperature °C.	Polarization after heating.	Fall in Polarization = x	Log $\frac{a}{a - x}$	Log $\frac{a}{a - x}$ for water.	Difference of Cols. 4 & 5	$\frac{\text{Velocity at 135° C.}}{\text{Velocity at the specified temperature.}}$
105	77.9	.1	.0004	....	.0004	371.3
110	77.2	.8	.0035	....	.0035	46.76
115	76.2	1.8	.0079	.0030	.0048	33.86
120	74.9	3.1	.0137	.0065	.0072	22.63
125	71.0	7.0	.0315	.0190	.0125	12.89
130	59.8	18.2	.0874	.0596	.0279	5.81
135	27.0	51.0	.3817	.2198	.1618	1.00

TABLE XV.

Rate of inversion of cane sugar in the presence of $\frac{N}{2}$ Magnesium Sulphate. Initial polarization 78.0 Ventzke.

Polarization after complete inversion —22.0° Ventzke.

Temperature °C.	Polarization after heating.	Fall in Polarization = x	$\text{Log}\ \frac{a}{a - x}$	$\text{Log}\ \frac{a}{a - x}$ for water.	Difference of Cols. 4 & 5	$\frac{\text{Velocity at 135° C.}}{\text{Velocity at the specified temperature.}}$
100	77.3	.7	.0030	....	.0030	327.0
110	76.1	1.9	.0084	....	.0084	116.8
115	75.0	3.0	.0132	.0030	.0102	96.1
120	70.0	8.0	.0362	.0065	.0297	33.0
125	62.0	16.0	.0757	.0190	.0567	17.3
130	31.4	46.6	.2725	.0596	.2129	4.5
135	—15.7	93.7	1.2008	.2198	.9810	1.0

With the data thus obtained, I calculated values of A in the expression

$$C_1 = C_0 \, e^{\frac{A(T_1 - T_0)}{T_1 T_0}}$$

between C_{135} and the other temperatures, as for example; the value of A as calculated from the values of the rate of inversion at 125° C. and 120° C. for the alkaline chlorides will be found by solving the equation

$$.8259 = .0198 \, e^{\frac{A\ (408 - 393)}{408 \times 393}}$$

In Table XVI I have tabulated values of A so found.

TABLE XVI.

Connection between temperature and rate of inversion of cane sugar in aqueous solution and also in the presence of certain neutral salts.

	Water	Alkaline Chlorides.	Alkaline Sulphates.	Magnesium Sulphate
Temperature °C.	Value of A as between the specified temperature and 135° C.			
105	.....	31600	30500	28900
110	.....	31000	23400	28900
115	33900	36100	27700	34900
120	37800	39900	33200	35800
125	39800	46000	41500	43800
130	42900	50600	58000	45400

The values of A show in general a regular rise with increase of temperature, and the nature of the rise and the values obtained, whether in aqueous solution or in the presence of salts, is in all cases very similar. The irregular values obtained with alkaline sulphates are probably due to large percentage errors in the small readings.

These figures probably point to a constant value of A, for the data tabulated do not give the actual velocity of inversion at the specified temperature, but the velocity due to heating up to, say 130° C. and keeping at 130° C for half an hour. At the higher temperatures, then, the fall in polarization, and consequently the velocity of inversion, is proportionately greater than calculated from the data obtained.

THE ACTION OF NEUTRAL SALTS OF ALKALIES AT HIGH TEMPERATURES UPON DEXTROSE AND UPON LEVULOSE.

The isomeric changes that occur when hexose sugars are heated in the presence of alkalies and alkaline salts of weak acids are well known and have been studied chiefly by Lobry de Bruyn and by Van Ekenstein[6]. I thought, however, it of interest to examine the action of salts and alkalies at a high temperature on these bodies in view of their occurrence in considerable quantity in cane products.

In the first experiment 50 cc. of a 40%, by volume, solution of dextrose was heated at 130° C. for 30 minutes with 10 cc. of a 3 N solution of the salt. After heating the solutions were made up to 100 cc., the polariscope reading and the percentage of reducing sugars calculated as dextrose were obtained. The results are given in Table XVII. Assuming that dextrose and levulose only are present, from these data has been calculated the percentage of dextrose and levulose in the solution following the method given by Browne[7]. The results given in Table XVII, show that the isomerization of dextrose into levulose takes place to a very limited degree under the influence of the salts, such as the nitrates and chlorides of the alkalies and alkaline earths, is more pronounced with sulphates, such as sodium sulphate, and is very pronounced with salts of weak acids.

TABLE XVII.

Action of neutral salts in $\frac{N}{2}$ concentration on dextrose heated for thirty minutes at 130° C.

Salt.	Polarization.	Dextrose %	Levulose %	Sum of Dextrose & Levulose
Original Polarization	61.3	18.55	...	18.55
No Salt	58.3	18.17	.26	18.41
Potassium Nitrate	58.5	18.20	.23	18.43
Potassium Chloride	59.8	18.30	.10	18.40
Magnesium Nitrate	56.8	17.95	.43	18.38
Calcium Chloride	56.1	17.91	.48	18.39
Magnesium Sulphate	57.1	17.99	.44	18.43
Sodium Sulphate	51.4	17.41	.94	18.35
Potassium Oxalate	34.0	15.06	3.02	18.18
Potassium Sodium Tartrate	38.8	15.54	2.88	18.42

Simultaneously with the isomerization of dextrose and levulose, there appears to be some evidence of a very small actual destruction of the reducing sugars, but the destruction which occurs is so small as to be inappreciable in practice.

INFLUENCE OF ALKALIES UPON DEXTROSE AT ELEVATED TEMPERATURES.

From the previous work of Lobry de Bruyn and Van Ekenstein,[6] it is known that solutions of dextrose and of levulose when heated in the presence of alkalies suffer an isomeric change, glucose and levulose being mutually converted into each other.* The recent work of Geerligs[8] has shown also that with prolonged heating an actual decomposition of the reducing sugars occurs. Since this decomposition leads to the formation of organic acids which in the presence of lime form objectional calcic salts, it was of importance to see how great was this decomposition at high temperatures. Accordingly, 50 cc. of a 20%, by volume, of a solution of dextrose was heated at 130° C. for half an hour with from 1 cc. to 10 cc. of $\frac{N}{5}$ caustic soda, the total volume of the solution being in all cases 60 cc. The results obtained are given in Table XVIII. In the solutions after making up to 100 cc. were determined the polarization and the reducing sugars as dextrose whence has been calculated after Browne the quantities of dextrose and of levulose. From the results given the following conclusions are to be drawn:

TABLE XVIII.

Action of varying amounts of caustic soda on dextrose at 130° C.; time of heating thirty minutes, volume of solution 60 c. c.

C. C. $\frac{N}{5}$ Caustic Soda	% Dextrose.	% Levulose.	Sum of Dextrose & Levulose.	Sugars after heating % on original.
Original	9.20	...	9.20	...
1	6.30	2.45	8.75	95.1
2	5.90	2.81	8.71	94.7
3	5.79	2.81	8.60	93.5
4	5.70	2.83	8.53	92.7
5	5.52	2.80	8.32	90.4
6	5.53	2.75	8.28	90.0
7	5.37	2.86	8.23	89.5
8	5.29	2.87	8.16	88.7
9	5.25	2.89	8.14	88.5

---

* The isomeric changes into which the sugars suffer under certain conditions (dynamic isomerism) is a subject of great interest and importance. The purely academic side of this question has little bearing on the manufacture of cane sugar; and for further information, the papers of Lowry and of Hudson appearing during the last few years in the Journals of the Chemical Society of London and of the American Chemical Society respectively, may be consulted.

1. With half an hour's heating at 130° C. dextrose is, in the presence of dilute alkalies, converted in a mixture of dextrose and levulose, the dextrose being in excess of the levulose in a ratio varying from 6.3 : 2.4 to 5.2 : 2.9 depending on the amount of alkali present.

2. Simultaneously a certain amount of reducing sugar is destroyed as such, the amount destroyed increasing with increase of alkali.

3. The amount of reducing sugar destroyed is, however, small and would not be sufficient to cause any trouble under the conditions of cane sugar manufacture.

Following on this experiment, I prepared a solution of invert sugar, the invert sugar was prepared by the action of sulphuric acid (5 cc. of acid per 100 cc. of 20% by volume of sugar) at the temperature of 70° C. After complete inversion the acid was neutralized by barium carbonate and the invert sugar solution filtered free from the sulphate and excess of carbonate.

The resulting invert sugar solution was treated precisely as in the above experiment with the results shown in Table XIX. The action and final state of equilibrium between dextrose and levulose is very similar to that found when dextrose alone was heated and the same conclusions as regards the action of high temperatures on cane juices are to be deduced.

TABLE XIX.

Action of varying amounts of caustic soda on invert sugar at 130° C.; time of heating thirty minutes, volume of solution 60 c. c.

Caustic Soda C. C. $\frac{N}{5}$	% Dextrose.	% Levulose.	Sum of Dextrose & Levulose.	Sugars after heating % on original.
Original	5.53	5.53	11.06	...
1	6.99	3.82	10.81	97.8
2	6.96	3.50	10.46	94.6
3	6.88	3.48	10.36	93.7
4	6.79	3.46	10.25	92.7
5	6.75	3.42	10.17	92.0
6	6.70	3.40	10.10	91.3
7	6.66	3.39	10.05	90.9
8	6.58	3.38	9.96	90.1
9	6.55	3.35	9.90	89.6

TABLE XX.

Action of high temperatures on cane juices in the presence of varying quantities of lime; total volume of solution 70 c. c.; time of heating thirty minutes; polariscope reading taken in 100 c. c.

C. C. N/5 Lime Emulsion	Temperature and Pressure above Atmosphere. Lbs. per sq. in.							
	100° C. 212° F. 0.0	105° C. 221° F. 2.8	110° C. 230° F. 6.1	115° C. 239° F. 9.8	120° C. 248° F. 14.1	125° C. 257° F. 19.0	130° C. 266° F. 24.5	135° C. 275° F. 30.7
Original Polarization								
0	39.8	39.8	39.8	39.8	39.8	39.8	39.8	39.8
2	Polarization constant	39.3	39.2	38.1	37.5	35.8	34.7	30.2
5		39.6	39.6	38.8	38.1	36.6	35.3	32.9
7		39.8	39.7	39.2	39.1	38.3	37.8	33.7
10		Polarization constant	39.8	39.5	39.4	39.2	38.6	37.4
12			Polarization constant	39.8	39.8	39.4	39.0	37.7
15				Polarization constant	Polarization constant	Polarization constant	39.2	38.2
17							Polarization constant	38.7
20								Polarization constant

EXPERIMENTS WITH JUICES.

The experiments described above determined the changes which take place in sugar solutions at elevated temperatures in the presence of alkalies, salts of inorganic and organic acids. The behavior of cane juices will of course depend in part on the salts originally present, but in view of the experiments described above the dominant factor will be the amount of alkali present in practice, that is to say, the amount of lime used in clarification.

An experiment made on a cane juice is described below. Fifty cubic centimeters of a cane juice were treated with from 0 to 20 cc. of a $\frac{N}{5}$ emulsion of lime; the juices, after making up to a volume of 70 cc., were heated for 30 minutes at the temperature specified in Table XX. After cooling they were all treated with the same quantity of basic lead acetate made up to 100 cc. filtered and polarized.

Clarification (in its factory sense) with this juice would have been made with a quantity of lime equal to from 7 cc. to 12 cc. of the $\frac{N}{5}$ emulsion, depending on the caprice of the operator, though in some cases the writer has seen with juices as the above larger quantities of lime employed.

The results obtained with cane juice are completely in accordance with those obtained with sugar and water, alkalies and salts. At temperatures above 120° C. a point occurs at which there is a minimum inversion not affected by increasing quantities of alkali; at temperatures of 120° C. and below, no inversion is detectable provided a sufficient amount of alkali is present.

THE EFFECT OF HIGH TEMPERATURES ON THE CLARIFICATION OF JUICES.

Although the main object of the experiments detailed above was to obtain information on the behavior of cane sugar when heated in the presence of such bodies as occur in juices, it was thought of some interest to study the clarification of juices at temperatures above 212° F. By clarification is included here such points as the volume occupied by the mud or precipitate formed on liming, the rapidity of settling, the brightness of the juice, the viscosity, and the rapidity of filtration. Accordingly, a quantity of juice was limed under such conditions as obtain in practice, the actual amount of lime used being .15% on the weight of the juice; 500 cc. of this limed juice was then placed in litre beakers and heated to 100° C.. 105° C., 110° C., 115° C., 120° C., 125° C., 130° C., in an autoclave; in order to obtain a rapid heating similar to what would happen in a tubular heater, such as is commonly employed, the smallest safe quantity of water was placed in the autoclave, and this was heated to boiling before placing in the juice under examination. As soon as the temperature reached the desired point, the source of heat was removed and the valve opened to allow the pressure and temperature to fall rapidly. After cooling, the juices were made up to original bulk and examined as regards the following points:

a. *Brightness.*—The juice clarified at 100° C. was fairly bright; that clarified at 105° C. was brighter; and those clarified at 110° C. to 130° C. were all of equal brightness.

b. *Volume of Precipitate.*—The volume of the precipitate of the juices clarified at 100° C. and 105° C. was about 10% greater than that of the others between which no difference was observable.

c. *Rapidity of Settling.*—No appreciable difference was noted except that in the case of the juices clarified at 100° C. and 105° C. some scum remained floating on the surface and refused to sink.

d. *Effect on Purity.*—The analysis of the juices (total solids from refractometer and direct polarization) gave identical figures in all cases. From what has already been written, some destruction of sugar at the more elevated temperatures must have occurred, but a comparison of the results obtained with a thirty-minute heating will show that the loss would be undetectable with a heating of two minutes' duration.

e. *Viscosity of Juices.*—The clear supernatant liquid was separated from the mud and examined in a flow viscosimeter. The results are given in seconds for the flow of 200 cc. under identical conditions.

Temperature of Clarification, C°.	Time of Flow, Seconds.
100	236
105	235
110	237
115	238
120	235
125	237
130	236

From this experiment then it is safe to conclude that the temperature at which clarification is effected has no effect on the viscosity of the resulting clear juice.

f. *Rapidity of Filtration.*—The mud from all the juices was collected separately and was finally obtained in each case collected in a volume of 130 cc. A Buchner funnel 10 cm. in diameter was arranged over a vacuum receiving flask, and on the plate of the Buchner funnel a piece of filter paper (Schleicher & Schull No. 597) was placed. After starting the vacuum pump, the whole 130 cc. of mud and juice were thrown on to the filter. After the lapse of five minutes the pump was stopped and the amount of juice which had passed through was measured. The results obtained are given below:

Temperature of Clarification, C°.	Volume of juice in cubic centimeters passing in five minutes through a filtering area of 74 square centimeters of S. & S. filter paper, under a pressure of about 13 lbs. per sq. in.
100	99
105	98
110	99
115	97
120	98
125	97
130	97

As with the viscosity tests, the results are very nearly the same and go to show that the temperature has little effect on clarification.

g. *Amount of Precipitate Formed.*—Since it had been found that the purity in all cases was the same, it naturally follows that the amount of non-sugar removed from solution is also the same. To experimentally test this point in another way, the mud from 500 cc. of juice clarified at different temperatures was collected, washed, dried, and weighed. The results obtained are given below:

Temperature of Clarification, C°.	Dry Weight of Precipitate, Grams per 500 c. c. of Juice.
100	1.832
105	1.804
110	1.810
115	1.822
120	1.828
125	1.820
130	1.816

These weights are nearly identical and show that the temperature has no effect on the amount of non-sugar precipitated by the action of lime in clarification. It may be remarked that these weights of mud are much less than are obtained in the dry press cake in regular factory work. In the latter case fiber due to the milling process and dirt attached to the canes increase the weight of the press cake. The juice used in these experiments was first strained through linen bags.

ON THE STERILIZATION OF JUICES AND REMELTED SUGARS.

In a previous publication from this Station the connection between deterioration of sugar on storage and in transit and the presence of bacteria was discussed. It was there shown that sugars which contained less than 1% of water did not suffer deterioration even when infected with very large numbers of bacteria. The very great proportion of sugar shipped from these island contains less than 1% of water, and complaints of deterioration are now uncommon, although occasionally a loss from this cause comes to the notice of this Station. It was for this reason thought advisable to examine the possibility of obtaining sterile juices through the application of high temperatures.

Some preliminary work in this connection has been described in a previous publication wherein it was shown that the raw juice contained a very large number of bacteria, some of which survived the passage through the boiling house. In addition, the low grade sugars stored over long periods were found to be invariably infected with large numbers of bacteria, and the introduction of these sugars whether remelted or as seed will serve to add organisms to those originally present in the juice and which have survived the passage through the boiling apparatus. The starting point in this investigation was a typical low grade sugar of age one year from the time that it was struck into receivers. It was of polarization about 85 and slightly acid in reaction. A count of the number of organisms which developed on plating out showed that it contained about 100,000 bacteria per gram. It was therefore a suitable sugar for the purpose of the experiment which was to determine the temperatures and duration of heating necessary to kill the bacteria inhabiting the sugar. The routine of the determinations made was as follows:

A 5% solution of the sugar was made up and 2 cc. of this solution was seeded into 10 cc. of melted nutrient agar agar contained in test tubes. The tubes and their contents were then placed in an autoclave in which the water was already boiling under atmospheric pressure. They were then kept for the time and at the temperatures given in the tables below. Immediately on removing from the autoclave the contents of the tubes were poured into

Petri dishes and incubated at 30° C. After 24 hours the number of colonies which developed were counted. The results obtained are tabulated below and give the average of three experiments:

NUMBER OE ORGANISMS REFERRED TO ONE GRAM OF SUGAR.

	Temperature and Pressure above Atmosphere; Pounds per sq. in.					
Time in	**100.° C.**	**105° C.**	**110° C.**	**115° C.**	**120° C.**	**125° C.**
Minutes	**212° F.**	**221° F.**	**230° F.**	**239° F.**	**248° F.**	**257° F.**
	0	**2.8**	**6.1**	**9.8**	**14.1**	**19.0**
0	**About 100,000**					
5	**13,000**	**3,050**	**1,600**	**800**	**230**	**Sterile**
10	**12,300**	**2,620**	**970**	**120**	**Sterile**	**Sterile**
15	**10,900**	**2,410**	**200**	**Sterile**	**Sterile**	**Sterile**
20	**10,800**	**2,020**	**Sterile**	**Sterile**	**Sterile**	**Sterile**
25	**8,010**	**1,900**	**Sterile**	**Sterile**	**Sterile**	**Sterile**
30	**7,700**	**1,790**	**Sterile**	**Sterile**	**Sterile**	**Sterile**

This experiment does not give the actual effect of the temperature entered, for in addition to the time over which the sugar was kept at the specified temperature must be added the time taken to reach that temperature; this was observed and found to be

From 100° to 105° C., 3 minutes
" 100° to 110° C., 6 minutes
" 100° to 115° C., 10 minutes
" 100° to 120° C., 15 minutes
" 100° to 125° C., 21 minutes

An experiment was then made to determine the thermal death point of the bacteria occurring in low sugars. It was found that 250 cc. of water was the minimum quantity which could be placed in the autoclave and allow the temperature to be rapidly raised without burning out the bottom of the apparatus. Accordingly, this quantity of water was placed in the autoclave and raised to the boiling point under atmospheric pressure. Nutrient agar agar tubes infected with 2 cc. of a 5% solution of the low sugar and contained in a beaker of water at the boiling point were placed in the autoclave which was rapidly closed and heated by six bunsen burners of the general laboratory pattern. A rapid elevation of temperature, designed to simulate the action of a live steam tubular heater was thus obtained. When the desired temperature was reached, the gas was turned off and the valve of the autoclave opened full so as to allow the temperature to fall rapidly. The results obtained are given below:

Heated from 100° C.		Seconds.	Number of Bacteria per Gram of Sugar.
105° C.	in	40	Very many
110° C.	in	93	Very many
115° C.	in	155	2010
120° C.	in	265	1500
125° C.	in	390	0

On examining the organisms in the colonies which developed on incubation after heating to the more elevated temperatures, it was found that only one type was present. Subcultures were made from a number of these, and in all cases a pure culture of that organism described by Lewton-Brain and the present writer as Bacillus C was obtained. This organism is a spore forming bacillus, and was found to cause rapid deterioration in sugars, combined with the formation of large quantities of gums.

Having determined the temperature and duration of heating necessary to obtain sterility in low sugars, experiments were made to determine the effect of elevated temperatures on such bodies both as they actually exist and in the presence of small quantities of alkalies. The experiments were made precisely as described when studying the action of elevated temperatures on cane sugar with the following results specified below.

A 40% solution of the low sugar had an acidity equal to 4cc. $\frac{N}{10}$ acid per 100 cc. of solution; 50 cc. of a 40% solution of this sugar was heated for 30 minutes in the presence of varying quantities of alkali with the following results.

C°

100 Inversion was not detected with the addition of no alkali.

105 Inversion was not detected with the addition of 2 cc. $\frac{N}{10}$ alkali.

110 Inversion was not detected with the addition of 4 cc. $\frac{N}{10}$ alkali.

115 Inversion was not detected with the addition of 6 cc. $\frac{N}{10}$ alkali.

120 Inversion was not detected with the addition of 8 cc. $\frac{N}{10}$ alkali.

125 Inversion was at a minimum with the addition of 10 cc. $\frac{N}{10}$ alkali.

130 Inversion was at a minimum with the addition of 12 cc. $\frac{N}{10}$ alkali.

135 Inversion was at a minimum with the addition of 14 cc. $\frac{N}{10}$ alkali.

Since in the experiments on the temperatures and direction of heating necessary to obtain sterility it was found that the thermal death point occurred at 125° C., it can be said that low sugars in solution can be absolutely sterilized by momentarily heating to 125° C. without a detectable loss of sugar provided that the heating is effected in the presence of a certain quantity of alkali.

ON THE NATURE OF ACIDS.

In this publication and in a previous one, the action of neutral salts on the inversion of cane sugar both in the presence of acids and aqueous solution has been examined. The accelerative action of the halides and nitrates of the alkalies and alkaline earths first noticed by Arrhenius[10] has been examined in detail. It was found that there was a progressive increase in the accelerative action from chloride to bromide to iodide; and that of the bases examined, no difference in the acceleration was noticed due to the influence of the bases. With sulphates and all alkaline salts of weaker acids, a retardation of the rate of inversion occurs.

The acceleration of the rate of inversion of cane sugar by acids due to the presence of neutral salts, is directly opposed to the ionic hypothesis under which the concentration of the hydrogen ions (to the presence of which the properties of acids are stated to be solely and entirely due) is diminished in the simultaneous presence of a neutral salt of the acid. This behavior is explained by Arrhenius on the assumption that the "active mass"* of the cane sugar is increased by the presence of the neutral salt; indeed, he carries the ionic hypothesis so far as to calculate the theoretical rate of the inversion due to the calculated number of hydrogen ions present, the concentration of which is depressed by the simultaneous presence of the neutral salts.

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* When a body is in solution, it is hard to obtain a conception of a variation in the active mass unless the dissolved body is conceived as consisting of associated molecules which break into simpler molecules under the action of a change in the solvent, as by the presence of a neutral salt. An analogy to this conception would be the increase in the exposed area (active mass) of the sides of a solid obtained by cutting any solid into two pieces.

Other explanations of this accelerative action are that the neutral salt "stimulates" the activity of the hydrogen ions and that the addition of the neutral salt has a "concentrating" effect produced by the combination of the salt with water.

It was shown by Long[11] that salts of the heavy metals produce inversion and act in a way similar to acids. This inversion is explained as a hydrolysis under the equation

$$\dot{M} + X' + H.OH \rightleftharpoons M.OH + X' + \dot{H}$$

whereby the salt of a strong acid and weak base is split up in solution into the base and free hydrogen ions and free acid radicle ions. In this way there is supposed to be introduced into the solution free hydrogen ions to which the acid properties of a salt, such as zinc chloride in solution, are due.

The inversion of cane sugar under the influence of neutral salts of the type of sodium chloride in aqueous solution independent of the presence of an acid is usually stated not to occur. Apparently the influence of these bodies has been previously tested up to the arbitrary temperature fixed by the boiling point of water under atmospheric pressure. At temperatures very little above this the inversion of cane sugar under the influence of neutral salts is quite apparent and is so pronounced as to take place even in faintly alkaline solutions. Under these circumstances the presence of free hydrogen ions is (following the ionic hypothesis) impossible; and consequently the inversion of cane sugar under these conditions can not be due to the presence of hydrogen ions. Under the ionic hypothesis, all the properties of acids are referred to the properties of hydrogen ions, and the strength of an acid is regarded as due to the degree of dissociation. Similarly, the acid properties shown by salts, such as aluminum sulphate, zinc chloride, is referred to the formation of hydrogen ions on solution due to a process of hydrolysis.

Conversely, the properties of all bases are referred to the possession of an hydroxyl ion. Water itself is supposed to contain a limited number of free hydrogen and hydroxyl ions; and a dilute aqueous solution of cane sugar is, under the ionic hypothesis, supposed at ordinary temperatures to be slowly undergoing inversion, although the rate of change is so slow as not to be measurable even with a time interval of years. A very minute quantity of an acid will so accelerate this alleged rate of inversion that the rate of inversion in the presence of a trace of acid is greater than the rate of inversion in pure aqueous solution in much greater degree than has the concentration of the alleged hydrogen ions been increased by the addition of a trace of acid.

This behavior and the behavior of neutral salts at temperatures above the boiling point of water and of salts, such as zinc chloride at lower temperatures, can be explained on the idea that the properties of acids are *not* due to the hydrogen ions, but to the acid radicle; in the case of hydrochloric acid to the Cl, and that acidity is a specific property of certain elements (Cl, Br, I, etc.) or of certain groups of elements (SO_4, CH_3COO, etc.). Under this conception the role of hydrogen in those bodies referred to as acids is that of a vehicle for the conveyance of the acid radicles to which the properties of acids are due and the universal occurrence of hydrogen in those bodies usually referred to as acids, is because of its absence of properties whereby the acid properties of the acid radicle become apparent. On this conception, the acidity is a specific property of certain elements or radicles and the strength of different acids is due to this property and is not due to the concentration of the hydrogen ions.

Conversely, the properties of an alkali are not due to the possession of a hydroxyl group, but are specific to certain elements or groups, and the hydroxyl group acts as a vehicle for making these properties apparent precisely as hydrogen serves as a vehicle in acids. Following on this idea a certain specific alkalinity or acidity can be attributed to alkalies or acid elements or groups. When the specific alkalinity and acidity are nearly the same a neutral salt results through the combination; an alkaline salt results when an element (as sodium) of large specific alkalinity unites with a group, as CH_3COO, of low specific acidity; and an acid salt results in such combinations as $Al_2(SO_4)_3$, $ZnCl_2$.

Further, on this conception the non-inversion of cane sugar by water at ordinary temperatures, even though hydrogen ions are present, and its inversion by the addition of a trace of acid is explained, since the peculiar properties of acids are supposed not to be due to the hydrogen, but to the other part of the combination—that is to say, on adding a minute trace of an acid, say hydrochloric acid, to a sugar solution, we add hydrogen ions (for the moment, using the language of the ionic hypothesis). Hydrogen ions were originally present in the water and inversion did not occur, hence the inversion is due to the other thing added—that is to say, to the chlorine ions.

As regards the effect of neutral salts on accelerating the rate of inversion of cane sugar, it is to be noticed that in so far as regards the salts of the alkalies and alkaline earths, it is only the salts of the strongest acids that accelerate the rate of inversion, and that salts of weaker acids retard the rate of inversion. A salt consists of two parts,—one of which occurs in acids, and one of which occurs in bases. The acceleration or retardation should then be due to the combined effect of these two parts. If the specific effect of the acid part of salt is greater than the specific effect of the alkaline part of the salt, an acceleration will happen, the reverse obtaining when the specific effect of the alkaline part of a salt is the greater.

Thus, in salts of the nature of sodium chloride, typical representatives of a neutral salt, it is suggested that the specific acid effect due to the Cl is greater than the specific alkaline effect due to the Na. In a salt of the nature of sodium sulphate, also a typical neutral salt, the specific alkaline effect of the Na is greater than the specific acid effect of the SO_4. Similarly, in salts of the nature of aluminum sulphate the specific alkaline effect of the Al is so small compared with the specific acid effect of the SO_4 that an acid salt, easily recognizable as such, results; and with salts, such as sodium acetate, an alkaline salt results, due to the very small specific acid property of the CH_3COO group.

At once a difficulty arises in this conception of the nature of acids from certain experimental observations made in this publication and in a previous one (Bulletin 35 of this series). It was observed that at ordinary temperatures sulphates of the alkalies and alkaline earths and of ammonium, retarded the rate of inversion. At the temperature of boiling water ammonium sulphate causes inversion rapidly. At temperatures above the boiling point of water sulphates of the alkalies and magnesium sulphate cause the inversion of cane sugar. The inversion, due to ammonium salts generally, is usually stated to be due to the driving off of ammonia and an acid solution remaining. In my experiments, however, I was able to obtain inversion with ammonia salts in the presence of free ammonia, the solution after heating still remaining alkaline.

This behavior I would explain as follows: A salt consists of two parts,—the acid part (Cl, SO_4, etc.), and the alkaline part (Na, etc.). The specific effects of these two parts are a function of the temperature and are affected by temperature independently of each other. At ordinary temperatures the specific alkaline effect of NH_4, Na, etc., is greater than the specific acid effect of SO_4 and a salt of an alkaline nature (i. e., alkaline in so far as it retards the rate of inversion of cane sugar) results. With the rise of temperature the specific acid effect of SO_4 increases more rapidly than does the specific alkaline effect of NH, Na, etc., and eventually a salt with acid properties as evidenced by the inversion of cane sugar results. The difference in behavior between ammonium salts and salts of the alkalies and alkaline earths, then, resolves itself into a difference in the rate of increase of the specific alkaline effect due to a rise in temperature; in the case of ammonium salts, the rate of increase being less than in the case of the salts of the alkalies and alkaline earths.

Further, in support of the conception of a specific acid effect as a property of certain elements or groups, the behavior of acetic acid and the substituted mono-, di-, and tri-chloracetic acids may be mentioned. With these acids a progressive and very large rise in the strength of the acid occurs with each substitution of chlorine in the molecule. Under the ionic hypothesis this increase in the strength of the acid is stated to be due to an increased dissociation on solution. It is suggested that this behavior is really due to the specific acid effect of the chlorine which remains definite and pronounced, although the chlorine atom is not attached directly to a hydrogen atom.

A difficulty in the way of formulating this conception of the nature of an acid was the inversion which cane sugar undergoes at higher temperatures even in alkaline solution, and hence independent of a specific property of acids or of salts. This breaking down of the cane sugar molecule at high temperatures may be regarded as one independent of the inversion by acids, acid salts, and neutral salts. The identity of the products of the breaking down at high temperatures and those formed on inversion being accidental.

Finally, water is regarded as a neutral body. It is generally pictured as consisting as of the composition H.OH—that is to say, as made up of the bodies to which acid and alkaline properties are respectively due, and its neutrality may be ascribed to the exact neutralization of the acid properties of H· by the alkaline properties of ·OH.* On the other hand, the neutral properties of water may be regarded as due to the fact that the properties of the H · group and the ·OH are both neutral—i. e., the absence of any pronounced properties and that in acids and alkalies they serve simply the part of vehicles.

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* It is a matter of indifference in this argument whether ions exist or not, since for each H. ion there must be an .OH ion.

This view of the nature of acids and alkalies, referring their properties not to H · and ·OH, respectively, but to the other constituent of the molecule, receives confirmation from the work which has been done in recent years by Franklin and his associates on the properties of liquid ammonia; they have shown that when sodamide $NaNH_2$ is dissolved in liquid ammonia an alkaline solution results, and conversely that when acetamide $CH_3CO{\cdot}NH_2$ is dissolved in the same solvent an acid solution is obtained. As regards aqueous solution, caustic soda and acetic acid are the analogues; the constituent of the sodamide and caustic soda common to both bodies is Na ·, and it is to this constituent that the alkaline properties are to be attributed, the $\cdot NH_2$ in the case of sodamide dissolved in liquid ammonia serving as the inactive vehicle; indeed, in this case alkalinity due to ·OH is impossible, since it does not appear in this combination; a similar argument holds as between acetic acid and acetamide, attributing the acid properties of both to that constituent which appears in both combinations to the exclusion of the H · ion, which can only appear in the solution of acetic acid in water.

Summary.—In this publication the effect of high temperatures on cane sugar in solution has been studied, and it has been found:—

1. That at temperatures above 100 ° C. cane sugar is inverted even in alkaline solutions.
2. The inversion first becomes noticeable at about 110° C. and increases rapidly with increasing temperature.
3. The connection between rate of inversion at one temperature and at another is given by an expression of the form

$$C_1 = C_0 \, e^{\frac{A\,(T_1 - T_0)}{T_1 T_0}}$$

where C_1 and C_0 are the rates of inversion at T_1 and T_0; e is the base of the natural system of logarithm; and A is a constant of value about 35,000.

4. Chlorides, bromides, iodides, nitrates, sulphates of the alkalies and alkaline earths, materially increase the rate of inversion at high temperatures in neutral or in alkaline solutions.

5. The action of the neutral salts of the alkaline earths is much greater than is that of the neutral salts of the alkalies.

6. At high temperatures sulphates of the alkalies and alkaline earths, which at lower temperatures retard the rate of inversion, invert cane sugar.

7. Neutral salts of weaker acids act similarly to alkalies and retard inversion at high temperatures.

8. The dominant factor in determining the rate of inversion at temperatures above 100° C. is the amount of free alkali.

9. The inversion caused by varying quantities of neutral salt is proportional to the amount of salt present.

10. Wilhelmy's law of mass action does not hold as regards quantity of sugar inverted in unit time, but the rate of inversion increases with the time and is about thirty times as great for a thirty-minute period as for a five-minute period.

11. The system obtaining in cane juices is a very complex one, consisting of very variable amounts of salts of both strong and weak acids and of free alkali. Hence a temperature which may be safe with one juice may cause serious inversion in another. With the conditions usually prevailing in local factories, juices should suffer a half hour's heating at 120° with no detectable loss of sugar. It would be conservative to adopt this temperature as the highest to which cane juices should be subjected during the process of evaporation, though under a careful system of control and observation a temperature of 125° (or even 130° C. for shorter periods) might be permissible.

12. In the presence of neutral salts of strong acids at high temperatures the isomerization of dextrose is small. It is larger with sulphates of the alkalies and larger still with the alkali salts of weak acids.

13. In the presence of alkalies at high temperatures dextrose is isomerized into a mixture of dextrose and levulose. Simultaneously there is a fall in polarization. The dextrose is in excess of the levulose in proportion about 2:1; a portion of the reducing sugars is destroyed as such, the amount destroyed increasing with increase in alkali.

14. When invert sugar is heated under the same conditions as in 12, a portion of the levulose is isomerized to dextrose, the proportion of dextrose : levulose obtaining eventually being very similar to what obtains when dextrose alone is heated. As with dextrose, a portion of the reducing sugars

disappears and the destruction with invert sugar is comparable to the destruction when dextrose alone is heated.

15. Probably in the presence of alkali a fixed equilibrium between dextrose and levulose obtains, the position of equilibrium being rapidly obtained at high temperatures.

16. The sterilization of cane sugar products is possible, since it occurs almost instantaneously at 125° C., which is very close to the thermal death point of the most heat resistant sugar house bacteria, and since at this temperature in alkaline solution the inversion of cane sugar is very slow.

17. The effect of high temperatures on "clarification" is very small; the most that can be hoped for is a juice from which the dirt might be separated with a little more ease.

18. The dark coloration observed when cane sugar is heated at high temperatures in the presence of alkalies does not indicate a detectable destruction of sugar.

19. The use of high temperature evaporation and the pre-heater system of evaporation and also the sterilization of all cane sugar house products, is possible under a rational system of control.

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REPORT OF WORK
OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

Lysimeter Experiments

BY S. S. PECK

HONOLULU, HAWAII.
1911.

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AGRICULTURAL AND CHEMICAL SERIES. BULLETIN No. 37

REPORT OF WORK
OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

Lysimeter Experiments

BY S. S. PECK

HONOLULU, HAWAII.
1911.

SEP 11 1911

LETTER OF TRANSMITTAL.

To the Experiment Station Committee of the
Hawaiian Sugar Planters' Association,
Honolulu, Hawaii.

Dear Sirs:—I herewith submit for publication as Bulletin No. 37, of the Agricultural and Chemical Series, an article by Mr. S. S. Peck, Chemist, entitled "Lysimeter Experiments."

Yours very truly,

C. F. Eckart,
Director.

Honolulu, July 5, 1911.

LYSIMETER EXPERIMENTS.

By S. S. Peck.

The experiments reported in this bulletin have for their object principally the study of (1) the effect of various forms of lime on the formation of nitric nitrogen in an acid, mauka (upland) soil from a wet district of these Islands; and (2) the effect of various fertilizer salts alone and in combination on the formation of nitric nitrogen in an alkaline makai (lowland) soil from a district of limited rainfall. The results are not intended to be interpreted as giving any definite conclusions as to the effects of the various treatments on cane crop production. While from numerous experiments it has been fairly well established that the nitrogen more than the potassium or phosphorus is the "dominant" fertilizing constituent for cane crops, it is true only in a measure that conditions which make for increased production of nitric nitrogen will necessarily be accompanied by increased crop returns; it is possible in given cases that the best treatment on a soil with this object in view may result in unfavorable conditions for plant development or exert an ultimate harmful influence on the fertility of the soil. For this reason, while in this bulletin the tests will be classified according to the nitric nitrogen produced by the respective treatments, it must be thoroughly understood that they do not represent and cannot supplant actual trials in the field, with the weight of several crops and the condition of the soil after the crops as the deciding factors.

Soils Used. The upland soil was taken from the surface twelve inches of land not long under cultivation, at an elevation of 1700 feet on Hawaii on the windward side of the Island. It is high in organic matter, with a reaction acid to litmus, and of a loose, friable texture. The lowland soil came from Kauai, and was light red in color and alkaline to litmus. This latter soil has been under cultivation for some time, and had apparently received within a few seasons a liberal application of lime. It was of a porous texture, easily permeable to water. The soils were subjected to the usual analyses, with the following results:

SOLUBLE IN ONE PER CENT ASPARTIC ACID SOLUTION.

	Upland.	Lowland.
Lime	0.035%	0.290%
Potash	0.005%	0.0182%
Phosphoric Acid	Trace	0.0003%

AGRICULTURAL ANALYSIS.

	Upland.	Lowland.
Insoluble Residue	19.17	28.80
Soluble Silica	3.45	6.60
Ferric Oxide	23.12	18.08
Aluminic Oxide	13.90	26.44
Manganese Oxide	.12	.46
Lime	.85	.84
Magnesia	2.47	.84
Potash	.18	.51
Soda	.29	.94
Sulphuric Anhydride	.37	.13
Phosphoric Anhydride	.25	.38
Chlorine	.003	.027
Loss on Ignition	35.47	15.52
Nitrogen	.82	.27
Humus	17.41	6.80
Nitrogen % Humus	3.59	2.36
Humus Nitrogen % Soil	.63	.16

MECHANICAL ANALYSIS.

	Upland.	Lowland.
Loss on Ignition	49.17	27.72
Coarse Grits	.....	.23
Fine Grits	1.61	.53
Coarse Sand	.89	.65
Medium Sand	5.34	.85
Fine Sand	18.24	19.72
Coarse Silt	11.11	17.46
Fine Silt	12.87	25.28
Clay	.77	7.26
Clay*	.....	.88

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*Seven days subsiding.

BIO-CHEMICAL ANALYSIS.

Bacterial Count, Organisms per Gram Soil.

	Lipman's Synthetic Agar.	Beef Agar.
Upland	280,000	400,000
Lowland	5,000,000	1,400,000

Denitrification by 10 *grams of soil in Giltay's solution containing* 24.6 *milligrams nitric nitrogen per* 100 *cc.:*

	Milligrams Nitric Nitrogen Remaining in 100 cc.:	
	3 days.	6 days.
Upland	21.0	9.7
Lowland	None	None

Ammonification by 10 *grams of soil in one per cent peptone solution:*

	Milligrams Nitrogen as Ammonia.	
	7 days.	10 days.
Upland	71.4	87.9
Lowland	103.0	122.1

Nitrogen fixation by 10 *grams of soil in* 1½ *per cent mannite solution. Time,* 21 *days:*

	Milligrams Nitrogen.	Milligrams Nitrogen per gram of Mannite.
Upland	16.52	5.54
Lowland	26.94	8.98

Nitrification by 10 *grams of soil in Omeliansky solution containing* 47.6 *mgms. Nitrogen as ammonia per* 100 *cc.:*

	Milligrams Nitric Nitrogen per 100 cc.	
	28 days.	34 days.
Upland	13.6	18.1
Lowland	7.6	7.1

At the time of placing the soils in the lysimeters, the upland soil contained 51.6 per cent, and the lowland 4.6 per cent of water. The agricultural analysis is reported in terms of dry soil, the mechanical as air dry soil, and the aspartic and bio-chemical on the soil as placed in the containers. The humus determinations were made according to the methods of the Official Agricultural Chemists, Bulletin 107.

PLAN OF EXPERIMENTS.

The lysimeters were constructed of galvanized iron, painted inside with asphalt paint. Each lysimeter was two feet in height and eight inches in diameter. The bottom was perforated with small openings. and led into a funnel which was soldered to the bottom. The ring of the funnel formed a support on which the vessel rested. The bottom was covered with coarse sacking, on the top of which three inches of washed black lava sand were placed. In the upland series, twenty-five pounds of soil were sufficient to fill each lysimeter to within three inches of the top; the lowland soils, being of a higher specific gravity, weighed forty pounds to each container. Distilled water was used for draining purposes, an irrigation being performed at two weeks' intervals. A definite amount of water was used each time, the leachings being received in Winchester bottles and measured. These were analyzed for nitric, nitrous, and ammonia nitrogen, total mineral matter, lime, potash, and phosphoric acid, the total amount of each being recorded for each leaching.

SERIES A.—UPLAND SOIL.

The two series consisted of twenty-four lysimeters, twelve being given to the upland, and twelve to the lowland soil. The twenty-five pounds of the upland soil as placed in the lysimeter measured 955 cubic inches. From this it follows that an acre-foot of such a soil would weigh 1,970,000, or in round numbers 2,000,000 pounds. On this basis the lysimeters were treated as follows:

1—Nothing.
2—Air slaked lime.
3—Calcium carbonate.
4—Calcium sulphate.
5—Ammonium sulphate.
6—Ammonium sulphate and slaked lime.

7—Ammonium sulphate and calcium carbonate.
8—Ammonium sulphate and calcium sulphate.
9—Complete fertilizer.
10—Complete fertilizer and slaked lime.
11—Complete fertilizer and calcium carbonate.
12—Complete fertilizer and calcium sulphate.

The lime salts were proportioned so as to supply calcium oxide at the rate of a ton to the acre-foot. They were thoroughly mixed with each lot before being placed in the cylinders. The complete fertilizer was compounded so as to add nitrogen from ammonium sulphate, potash from the sulphate, and water-soluble phosphoric acid from double superphosphate, at the rate of 100 pounds of each to the acre-foot. The ammonium sulphate alone, in the same amount, and the complete fertilizer were stirred in the surface three inches of the respective soils after they were in the cylinders. It will be noticed that this series consists of three lots each of which was identical in all respects with the exception of the lime addition. The results were expected to show the effects of these materials on the nitrification of the natural or humus nitrogen of the soil, and on that of ammonium sulphate with and without the addition of potassium and phosphorus salts.

In neither this series nor the second were there determinable amounts of phosphoric acid present in the drainage waters, even when applied as superphosphate. This is doubtless due to the well known fixing power which the Island soils have on this substance, and the long column of soil through which the water percolated. The nitrous nitrogen was also present in very minute quantities, and in the figures which follow will be reported along with the nitric nitrogen.

On the first two irrigations, three liters of water were used, which amount was then reduced to two and a half liters, this giving a convenient quantity of leachings for analysis. The amounts of the various material removed at each irrigation will be seen from the following tables:

TABLE I.

Nitric Nitrogen in Drainage.

GRAMS.

Irrigation No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1......	.0184	.0280	.0252	.0310	.0366	.0416	.0273	.0366	.0298	.0315	.0367	.0418
2......	.0397	.0446	.0403	.0495	.0374	.0451	.0635	.0747	.0426	.0691	.0671	.0811
3......	.0275	.0320	.0309	.0355	.0320	.0573	.0486	.0630	.0430	.0412	.0616	.0802
4......	.0384	.0275	.0397	.0359	.0440	.0636	.0604	.0695	.0543	.0646	.0703	.0749
5......	.0211	.0253	.0227	.0230	.0400	.0454	.0519	.0598	.0471	.0610	.0549	.0705
6......	.0152	.0294	.0267	.0343	.0527	.0614	.0552	.0870	.0592	.0501	.0604	.0741
7......	.0234	.0255	.0312	.0340	.0630	.0752	.0537	.0528	.0662	.0386	.0532	.0729
8......	.0234	.0318	.0325	.0306	.0590	.0646	.0525	.0572	.0583	.0481	.0592	.0647
9......	.0183	.0277	.0307	.0273	.0471	.0549	.0500	.0536	.0400	.0403	.0417	.0437
10......	.0178	.0283	.0252	.0315	.0539	.0493	.0443	.0505	.0516	.0534	.0529	.0447
Total...	.2432	.3001	.3051	.3326	.4657	.5584	.5074	.6047	.4921	.4979	.5580	.6486

TABLE II.

Total Minerals in Drainage.

GRAMS.

Irrigation No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1...	.3374	.4741	.4450	.8003	.3760	.4590	.3806	.6700	.4151	.4153	.4244	.6021
2...	.6895	.8856	.8619	1.3529	.7088	.7752	1.0200	1.8320	.8980	1.1120	1.1360	1.5680
3...	.7722	.9452	.8825	1.4732	.9608	1.1346	.9746	1.6554	1.0005	1.0714	1.1096	1.5352
4...	.6045	.7318	.7138	1.2760	.9063	1.0864	.8450	1.6301	.8436	1.0591	1.1357	1.6617
5...	.5089	.6383	.6518	.9760	.8401	1.0168	.7250	1.6236	.8976	1.0294	1.0224	1.4501
6...	.5135	.6422	.6003	1.0446	.9495	1.2018	.7878	1.6269	.9391	1.1095	1.1003	1.3381
7...	.4905	.6623	.6078	1.1623	1.0468	1.1930	.8208	1.3059	.8047	.7771	.8466	1.1576
8...	.3710	.4624	.4553	.8144	.7146	.8094	.6800	1.2043	.7410	.5762	.6161	.9676
9...	.3296	.4320	.4275	.7823	.6720	.6870	.6422	1.1520	.6194	.5457	.5445	.8382
10...	.3287	.3938	.3969	.8317	.6921	.6019	.6336	1.1902	.6922	.6843	.5865	.8685
T'l..	4.9458	6.2677	6.0428	10.5137	7.8670	8.9651	7.5096	13.8904	7.8512	8.3800	8.5221	11.9871

TABLE III.

Calcium Oxide in Drainage.

GRAMS.

Irrigation No.	1	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1......	.0382	.0708	.0600	.1518	.0432	.0575	.0564	.1324	.0493	.0574	.0686	.1321
2......	.0453	.1019	.0935	.1807	.0650	.0715	.1000	.3084	.0804	.1188	.1132	.1988
3......	.0504	,0890	.0847	.1965	.0816	.1047	.0900	.2935	.0830	.1094	.0904	.1649
4......	.0394	.0745	.0733	.1798	.0739	.0994	.0830	.2825	.0657	.1034	.1075	.1942
5......	.0302	.0638	.0353	.1480	.0601	.0902	.0818	.2855	.0726	.1059	.1156	.1941
6......	.0285	.0561	.0487	.1542	.0654	.0989	.0853	.3007	.0763	.1022	.1170	.1935
7......	.0286	.0512	.0460	.1776	.0714	.1027	.0874	.2471	.0702	.0797	.1000	.1848
8......	.0201	.0411	.0366	.1323	.0539	.0758	.0698	.2340	.0571	.0565	.0681	.1476
9......	.0160	.0365	.0327	.1332	.0521	.0642	.0649	.2419	.0550	.0581	.0618	.1350
10......	.0169	.0355	.0312	.1540	.0545	.0610	.0605	.2453	.0591	.0673	.0575	.1363
Total...	.3136	.6204	.5420	1.6081	.6211	.8259	.7791	2.5713	.6687	.8587	.8997	1.6813

TABLE IV.

Potash in Drainage.

GRAMS.

Irrigation No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1......	.0095	.0158	.0103	.0198	.0045	.0156	.0100	.0161	.0112	.0131	.0132	.0203
2......	.0162	.0204	.0198	.0271	.0175	.0155	.0208	.0396	.0206	.0225	.0235	.0284
3......	.0155	.0213	.0196	.0274	.0204	.0208	.0201	.0305	.0197	.0234	.0229	.0287
4......	.0170	.0175	.0186	.0293	.0177	.0208	.0162	.0298	.0171	.0195	.0211	.0264
5......	.0109	.0160	.0153	.0194	.0153	.0171	.0157	.0262	.0173	.0193	.0198	.0259
6......	.0124	.0156	.0152	.0222	.0190	.0222	.0196	.0320	.0179	.0213	.0272	.0273
7......	.0109	.0159	.0167	.0237	.0213	.0208	.0197	.0268	.0198	.0200	.0206	.0311
8......	.0081	.0119	.0112	.0192	.0148	.0162	.0124	.0258	.0138	.0124	.0128	.0206
9......	.0076	.0106	.0117	.0165	.0144	.0125	.0135	.0253	.0145	.0139	.0130	.0215
10......	.0079	.0115	.0135	.0225	.0148	.0123	.0124	.0258	.0138	.0146	.0126	.0244
Total...	.1160	.1565	.1519	.2271	.1597	.1738	.1604	.2779	.1657	.1800	.1867	.2546

As already stated, the phosphoric acid in the drainage was present as mere traces or at times entirely absent. due to the fixation of this element by the soil. The ammonia nitrogen was likewise present in the drainage in very small amounts, owing to the absorptive action of the soil on this form of nitrogen. For this reason no tabulation has been made of the amounts removed. In the following tables the quantities of elements removed have been calculated to pounds per acre-foot of soil, an acre-foot being taken as 2,000,000 pounds. Stated in this manner it is believed that a readier comprehension can be obtained of the relative actions of the several additions. Since the final figures are affected only in the second decimal place, and to facilitate calculations, the ammonia and nitrous nitrogen are included with the nitric nitrogen.

TABLE V.

Nitric Nitrogen in Drainage.

Pounds per Acre-Foot of 2,000,000 Pounds.

Irrigation Number.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1......	3.3	4.9	4.5	5.5	6.5	7.4	4.8	6.5	5.4	5.6	6.5	7.4
2......	7.0	7.9	7.1	8.8	6.6	8.0	11.2	13.2	7.5	12.2	11.9	14.3
3......	4.9	5.7	5.5	6.3	5.8	10.1	8.6	11.1	7.7	7.3	10.8	14.2
4......	6.8	4.9	7.0	6.4	7.8	11.3	10.7	12.3	9.6	11.4	12.4	13.3
5......	3.8	4.5	4.0	4.1	7.1	8.0	9.2	10.6	8.4	11.1	9.7	12.4
6......	2.7	5.2	4.7	6.1	9.3	10.9	9.8	15.4	10.5	8.9	10.7	13.1
7......	4.1	4.5	5.5	6.0	11.3	13.3	9.5	9.3	11.7	6.8	9.5	12.9
8......	4.1	5.7	5.8	5.4	10.4	11.5	9.3	10.1	10.3	8.5	10.5	11.4
9......	3.2	4.9	5.5	4.9	8.3	9.7	8.9	9.5	7.1	7.1	7.4	7.7
10......	3.1	5.0	4.4	5.6	9.5	8.7	7.8	8.9	9.1	9.4	9.3	7.9
Total...	43.0	53.2	54.0	59.1	82.6	98.9	89.8	106.9	87.3	88.3	98.7	114.6

TABLE VI.

Total Minerals in Drainage.

Pounds per Acre-Foot of 2,000,000 Pounds.

Irrigation No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1......	59.5	83.6	78.5	141.1	66.3	81.0	67.1	118.2	73.2	73.2	74.9	106.2
2......	121.6	156.2	152.0	238.6	125.0	136.7	179.8	323.1	158.4	196.1	200.4	276.5
3......	136.2	166.7	155.7	259.8	169.5	200.1	171.9	292.0	176.5	189.0	195.7	270.8
4......	106.6	129.1	125.9	225.1	159.8	191.6	149.0	287.5	148.8	186.8	200.3	293.1
5......	89.8	112.4	115.0	172.1	148.2	179.3	127.9	286.4	158.3	181.6	180.3	255.8
6......	90.6	113.3	105.9	184.2	167.5	212.0	138.9	286.9	165.6	195.7	194.1	236.0
7......	86.5	116.8	107.2	205.0	184.6	210.4	144.8	230.3	141.9	137.1	149.3	204.2
8......	65.4	81.6	80.3	143.6	126.0	142.8	119.9	212.4	130.7	101.6	108.7	170.6
9......	58.1	76.2	75.4	140.0	118.5	121.2	113.3	203.2	109.2	96.2	96.0	147.8
10......	58.0	69.5	69.0	146.7	122.1	106.2	111.8	209.9	122.1	120.7	103.4	153.2
Total...	872.3	1105.4	1064.9	1856.2	1387.5	1581.3	1324.4	2449.9	1384.7	1478.0	1503.1	2114.2

TABLE VII.

Calcium Oxide in Drainage.

Pounds per Acre-Foot of 2,000,000 Pounds.

Irrigation No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1......	6.7	12.5	10.6	26.8	7.6	10.1	10.0	23.3	8.7	10.1	12.1	23.3
2......	8.0	18.0	16.5	31.9	11.5	12.6	17.6	54.4	14.2	20.9	20.0	35.1
3......	8.9	15.7	14.9	34.7	14.4	18.5	15.9	51.9	14.6	19.3	15.9	29.1
4......	7.0	13.2	12.9	31.7	13.0	17.5	14.6	49.8	11.6	18.2	19.0	34.2
5......	5.3	11.3	6.2	26.1	10.6	15.9	14.4	50.3	12.8	18.7	20.4	34.2
6......	5.0	9.9	8.6	27.2	11.5	17.4	15.1	53.0	13.4	18.0	20.6	34.1
7......	5.0	9.0	8.1	31.3	12.6	18.1	15.4	43.6	12.4	14.1	17.6	32.6
8......	3.5	7.2	6.5	23.3	9.5	13.4	12.3	41.3	10.1	10.0	12.0	26.0
9......	2.8	6.4	5.8	23.5	9.2	11.3	11.4	42.7	9.7	10.3	10.9	23.8
10......	3.0	6.3	5.5	27.1	9.6	10.8	10.7	43.2	10.4	11.9	10.1	24.0
Total...	55.2	109.5	95.6	283.6	109.5	145.6	137.4	453.5	117.9	151.5	158.6	296.4

TABLE VIII.

Potash in Drainage.

Pounds per Acre-Foot of 2,000,000 Pounds.

Irrigation No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1......	1.7	2.8	1.8	3.5	0.8	2.7	1.8	2.8	2.0	2.3	2.3	3.6
2......	2.9	3.6	3.5	4.8	3.1	2.7	3.7	7.0	3.6	4.0	4.1	5.0
3......	2.8	3.7	3.5	4.8	3.6	3.7	3.5	5.4	3.5	4.1	4.0	5.1
4......	3.0	3.1	3.3	5.2	3.1	3.7	2.9	5.3	3.0	3.4	3.7	4.7
5......	1.9	2.8	2.7	3.4	2.7	3.0	2.8	4.6	3.1	3.4	3.5	4.5
6......	2.2	2.8	2.7	3.9	3.3	3.9	3.4	5.6	3.1	3.7	4.8	4.8
7......	1.9	2.8	2.9	4.2	3.8	3.6	3.5	4.7	3.5	3.5	3.6	5.5
8......	1.4	2.1	1.9	3.4	2.6	2.9	2.2	4.6	2.4	2.2	2.3	3.6
9......	1.4	1.9	2.1	2.9	2.6	2.2	2.4	4.5	2.6	2.5	2.3	3.8
10......	1.4	2.0	2.4	4.0	2.6	2.2	2.2	4.5	2.4	2.6	2.2	4.3
Total...	20.6	27.6	26.8	40.1	28.2	30.6	28.4	49.0	29.2	31.7	32.8	44.9

The addition of calcium in all forms made for an increase in nitric nitrogen, both from the organic nitrogen of the soil and from nitrogen added as sulphate of ammonia. There was no decided difference between the effect of caustic lime and carbonate of calcium, while the sulphate produced a greater amount of nitric nitrogen than the other lime treatments. This result is quite at variance with those reported in a previous series of lysimeter experiments,[1] where the effect of the sulphate of calcium was to depress nitrification. The difference in results is to be attributed entirely to the difference in the type of soils treated. As will be seen in the second series of experiments, a soil already alkaline to litmus and to which caustic lime was added, produced less nitric nitrogen from ammonium sulphate than where no addition of lime was made. The possible solution of this condition is given in connection with this second series. The soil in series A is an acid soil, rich in organic matter, and the effect not only of the alkaline lime compounds, but also of the sulphate of calcium, could be expected to give results not corresponding with those from a soil poorer in organic matter and basic or even neutral to litmus. The action of gypsum on soils has been found to be, as Storer expresses it,[2] very capricious. As regards its effect on nitrification, Wolff, Fittbogen and Deherain obtained negative results. while Warrington and Pichard found that nitrification was promoted. It is most probable that the sole cause of such greatly divergent conclusions rests with the difference in the types of soils forming the bases of the experiments, just as at this station, working with two distinct types of soils, diametrically opposite results were obtained.

The general effect of the calcium additions were the same, whether the lime compounds were added to the soil alone, or to the soil where ammonium sulphate, or a complete fertilizer was added. Where no manurial substance was added, the calcium oxide and carbonate increased the nitric nitrogen produced an average of 24 per cent over the untreated test, while the increase due to gypsum amounted to 37 per cent. When 100 pounds of nitrogen as ammonium sulphate were added, it becomes a matter of difficulty to state how much of the nitric nitrogen in the drainage originated with the ammonium salt and how much from the organic nitrogen of the soil. That in the duration of the experiment ammonification and subsequent nitrification of this original soil nitrogen did occur is evidenced by the amounts of nitrogen as nitrate found in tests 8 and 12, which exceeded by 6.9 and 14.6 pounds, respectively, the quantity added as ammonium sulphate. The general results can therefore perhaps be best compared from the total and average figures of the several methods of calcium treatments. These figures will be found in Table IX and graphically illustrated on Chart 1.

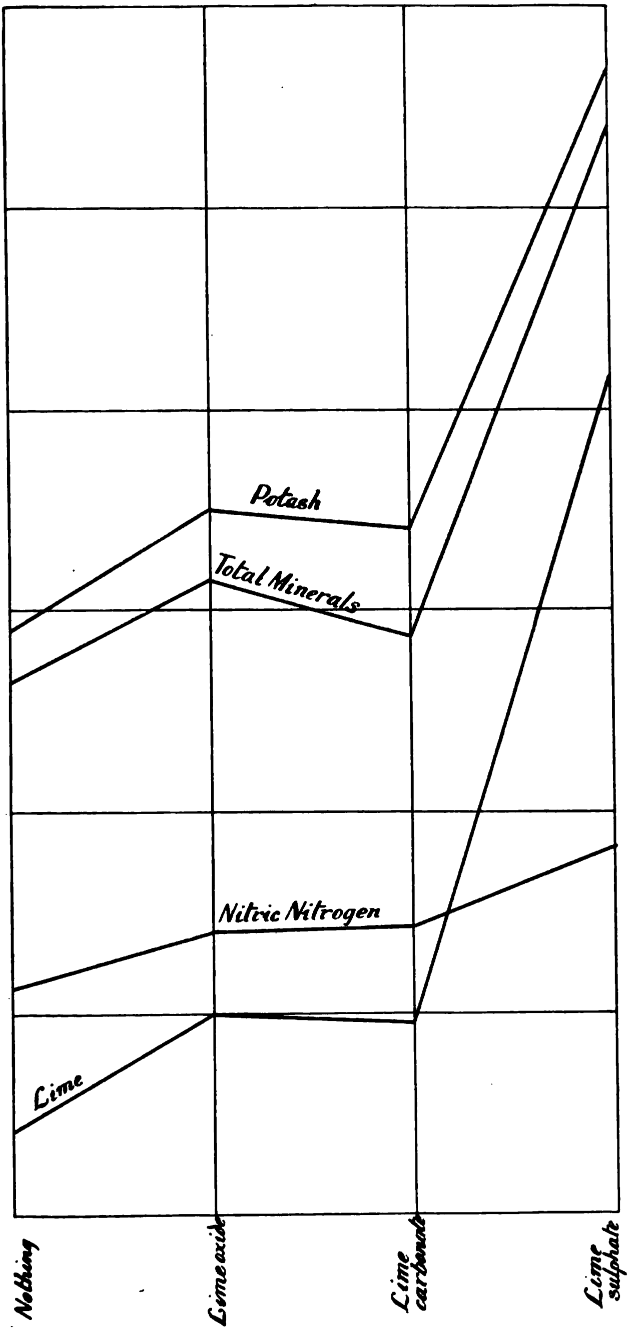
TABLE IX.

Pounds removed per acre-foot of 2,000,000 *pounds.*

	Nitric Nitrogen		Total Minerals		Lime		Potash	
	Total	Average	Total	Average	Total	Average	Total	Average
Nothing	212.9	71.0	3644.5	1214.8	282.6	94.2	78.0	26.0
Calcium Oxide	240.4	80.1	4164.7	1388.2	406.6	135.5	89.9	30.0
Calcium Carbonate	242.5	80.8	3892.4	1297.5	391.6	130.5	88.0	29.3
Calcium Sulphate	280.6	93.5	6420.3	2140.1	1033.5	344.5	134.0	44.7

The increase in nitric nitrogen due to the lime treatments amounted to 12.8, 14.1 and 31.7 per cent, respectively, the sulphate of calcium thus producing over twice as much increase as did the other lime salts. Previous to the treatments. the soil was acid to litmus. At the expiration of the experiments those pots treated with caustic and carbonate of lime were neutral, while the check and gypsum tests were decidedly acid. We have here the phenomenon of a treatment which corrects acidity producing a less increase in nitrification than one which has no corrective action. The question arises, does the addition of the lime compounds act as an impetus to nitrification by correcting the soil acidity, by adding soluble calcium salts to the soil water, or by releasing potash salts from their insoluble condition? This question will be more fully discussed after considering the effect of these additions on the amounts of lime and potash made soluble and found in the drainage waters.

Chart 1.


Potash
Total Minerals
Nitric Nitrogen
Lime
Nothing
Lime oxide
Lime carbonate
Lime sulphate

CALCIUM IN DRAINAGE.

Test 1, with nothing added, gave 55.2 pounds per acre of calcium oxide in the drainage. When 100 pounds of nitrogen as ammonium sulphate was added, along with an increase of 39.6 pounds of nitric nitrogen, there was a gain of 54.3 pounds of calcium oxide in the drainage. This increase may have been due to a substitution by the ammonia of calcium in the soil, the formation of soluble calcium sulphate, and its recovery in the leachings. Or the increased nitric oxide formed during nitrification combining with the lime in the soil, raised the soluble amount; or again it may be the combined effect of both reactions. Where lime was added, the increase in nitric nitrogen was accompanied by a corresponding increase in lime leached out; the soluble sulphate gives the most, followed in order of their solubilities by the oxide and carbonate. These results almost warrant the conclusion that the amount of nitrification is controlled by the amount of calcium salts found in solution in the soil water. Attention must be called to the large amount of lime in test 8, greatly exceeding that in test 12. This irregularity cannot be explained; it is accompanied by a similar irregularity in the total mineral and potash contents.

POTASSIUM IN DRAINAGE.

All the calcic compounds manifest a solvent action on the potassium of the soil, the sulphate exerting the greatest effect. This brings us to the consideration of the cause of increased crop returns following a gypsum fertilization, since such a beneficial action is ascribed generally to the fact that the calcium in this form replaces potassium in its insoluble combinations in the soil, making the latter available to the crop. Hall[3] mentions that in experiments with hops, only such soils as responded to a potash treatment responded to a gypsum application. Boussingault concluded from field tests that it was to the lime itself that the beneficial action was due, but Storer asks, "Why is gypsum a better fertilizer than lime itself, and why does it do good service in soils already well supplied with lime?" As may be seen from Table IX and Chart 1, increase in lime in drainage waters was accompanied by increase in potash. Comparing the nitrogen figures on Table V with the potash figures of Table VIII, it will be seen that the nitric nitrogen and soluble potash generally increased together. More nitric nitrogen meant more soluble calcium, and it may be due to this reaction that more soluble potassium resulted. It follows that the presence of soluble potassium was due to the degree or extent of nitrification, influenced by the amount of soluble calcium, and not that nitrification was dependent on the quantity of soluble potash. Reasoning from this, we must conclude that the effect of calcium sulphate in increasing nitrification is not caused by the potassium liberated by the calcium sulphate, but rather from the soluble calcium itself. In this connection it is interesting to refer to the results obtained in 1906.[1] The soil treated in this case was one of good lime content, the aspartic acid method giving a percentage of 0.327. The effect of ground coral was to increase nitrification slightly, but both burned lime and gypsum depressed it, the latter to a considerable extent. At the same time the potash made soluble by the gypsum was increased over two-fold. The author, in summing up the results, showed the close relationship existing between this result and the depressive effect of potash fertilization on cane crops. The soil in the experiments here reported showed only 0.035 per cent of lime soluble in a one per cent aspartic acid solution, and responded as regards nitrification very plainly and promptly to liming, especially with gypsum.

The results as regards the higher solubility of the potassium in soils treated with calcium compounds are not characteristic of all soils. Morse and Curry,[4] working with soils in New Hampshire, found that but little solvent action was manifest on the potash in the soils by either lime or gypsum. Bradley[5] found that with soils in Western Oregon, gypsum liberated potash, but lime did not. In the soil of our experiments all three forms showed their effects in increased amounts of potash in the drainage waters, the gypsum to the greatest degree, and the caustic and carbonate forms to about the same extent.

EFFECT OF POTASH AND PHOSPHORIC ACID IN ADDITION TO THE SULPHATE OF AMMONIA.

To the last four tests, in addition to the sulphate of ammonia, potash and phosphoric acid, at the rate of 100 pounds per acre-foot, were added, as sulphate and double superphosphate, respectively. In the unlimed and gypsum tests a small gain was effected in the nitric nitrogen; in the caustic lime and carbonate of calcium tests an irregularity arose which we cannot explain. In the first there was a loss of 11.6 pounds; in the second a gain of 8.9 pounds. There was a small increase in lime excepting between 8 and 12, the gypsum tests, where an extraordinary drop occurred, which cannot be explained by the presence of the added potash and phosphoric acid fertilizers, and must be attributed to some irregularity in the manner in which the soil was packed in one of the lysimeters, and a consequent difference in the manner of percolation of the water. Between the two sets but little difference between the potash contents of the drainage is evident. Since this material was added to the last four at the rate of 100 pounds to the acre-foot, the strong fixation power of our soils on this element is again displayed.

GENERAL OBSERVATIONS.

As mentioned at the beginning of the bulletin, the results as regards nitrate nitrogen produced do not entirely give an indication of what the crop yields will be. Therefore a few remarks on the general behavior of the different lime salts as observed by investigators in other stations may be of interest.

The practice of liming soils is one that extends to very ancient times; the reasons for the success attending the practice, however, have not yet been positively established. Working on different soils, with various crops, and under diverse climatic conditions, investigators do not concur in their conclusions as to any specific action of lime on soils. The various actions of lime may be briefly summarized as follows:

1. Plant Food. Lime is as essential a food for plant growth as nitrogen, phosphorus, or potassium. It is present, however, in enormous quantities on the surface of the earth, and usually in sufficient amounts for plant nutrition in all soils. It has not been the custom to conclude that in adding lime in any of its forms to a soil that the object is to supply lime to the crop, but rather the obtaining of one of its indirect effects.

2. Chemical. Lime has the power of replacing other min-

erals in their original combinations, changing them from insoluble and unavailable to soluble and available forms. This is particularly true of the mineral potassium, which exists largely in soils in the form of an insoluble silicate in conjunction with aluminum. The calcium in the lime takes the place of the potassium, which becomes available as plant food.

3. Physical. Lime possesses the somewhat paradoxical property of making heavy, clayey soils friable and pervious to water, and of making light, sandy soils closer and more retentive of moisture.

4. Biological. Most beneficial soil organisms functionate better in slightly alkaline than in acid media. Liming the soil with quicklime, slaked lime or carbonate of lime neutralizes any acidity existing in the soil and produces the more favorable alkaline reaction. Many plants themselves grow poorly or not at all in acid soils; whilst others, far fewer in number, seem indifferent in this respect.

Sources of Lime. Lime is used agriculturally chiefly as calcium oxide (quicklime, hydrated lime), calcium carbonate (shell, marl, coral), and calcium sulphate (gypsum or land-plaster). In addition it is found in combination with phosphorus in bone, rock-phosphate, slag-meal, etc., but these combinations are to be regarded only as suppliers of phosphoric acid, the addition of lime at the same time being merely incidental.

The use of lime in the United States is receiving the attention of many of the experiment stations on the mainland. Many positive results have been obtained in field tests, showing that beneficial results obtained on corn, wheat, clover, etc. There have also been cases where no benefit was derived and the attention of farmers has been called to the fact that too much lime is sometimes as bad as too little.

In liming a soil, the planter must not forget that he is supplying or adding to the land but little plant food. Rather, by unlocking the insoluble forms of the more valuable minerals, potassium and phosphorus, which are taken up by the crops or removed in the drainage waters, and by decomposing the nitrogenous matter or attacking the soil humus, he is obtaining present crop increase at the expense of later crops. Lime must always be regarded as an indirect fertilizer, or a stimulant, and conjointly with its use must go that of suitable fertilizer mixtures, in order to maintain a more permanent fertility of the soil.

The effect of the lime addition varies so greatly in different localities that the experience on one type of soil may be entirely contradicted by that in another. Thus, the effect of lime as quick or slaked lime has produced better results in some localities than when supplied as carbonate, while in other places the reverse obtains. Many experiments in the Eastern States have shown that for most crops gypsum is greatly inferior to the other lime compounds, but in Oregon very favorable results have been obtained by the use of this material.

Gypsum has been used successfully in correcting the effect of carbonate of sodium in black alkali soils, as evidenced by the extensive work performed by Hilgard in California. When sodium nitrate is used in large quantities, the result of the oppropriation of the nitrogen by the crop and the action of denitrifying organisms on the nitrate is frequently the formation of unfavorable amounts of bicarbonate of sodium, which, while not as noxious as the carbonate, is still a serious source of crop losses. It may act by deflocculating the soil particles and making bad physical conditions, by causing an excessive alkalinity interfere with bacterial action, or by having directly an adverse influence on the growing plant. In experiments with peas, Takeuchi[6] found that gypsum added to nitrate of soda as a fertilizer produced decided gains in crop yields over the tests where none was added, and ascribed the results to its correction of excessive alkalinity. On the contrary, tests with ammonium sulphate showed the opposite effect — the yields were lowered. Carpenter[7] found that both the carbonate and sulphate of calcium counteracted or neutralized the toxic effect of such salts as sulphate of magnesia, and the chloride, sulphate, or bicarbonate of soda, but the sulphate to the gréater extent.

Considerable work has been published by O. Loew on the importance of a correct ratio between lime and magnesia in soils. This theory has not become entirely accepted by agricultural investigators, but has been the subject of extensive research by Japanese scientists. In the same article quoted above, Takeuchi, in experiments with oats and spinach cultivated in soil to which magnesia was added, found that the sulphate of lime corrected the effect of the excess of magnesia, but the carbonate actually depressed the yield to an unusual extent.

In the use of calcium as oxide, or quicklime, care must be exercised not to make the application too large. Not only may there be no appreciable results, but an actual injury may be occasioned. In soils poor in humus, caustic lime destroys some of this valuable soil ingredient. Warrington found that limewater is a much stronger alkali than the nitric organisms can bear. Of course, the lime oxide is rather quickly transformed to the carbonate, when its harmful influence in this respect will disappear. The carbonate of calcium, on the contrary, has but little effect on the humus, and its solubility in water is so small that there would be no harmful results from even a considerable excess. Quicklime, or the carbonate, is frequently applied in conjunction with, or prior to, ammonium sulphate dressing. The rationale of this is that ammonium sulphate being physiologically acid, a base should be present to combine with the acid released. *Apriori*, some soils already basic will not be benefited.

As already mentioned, caustic lime will improve sandy soils by cementing the sand particles, and benefit clay soils by flocculation. The soils of these Islands cannot be properly placed under either of these categories. In some cases caustic lime has given undoubtedly good results on the physical condition of the soil; in other cases has worked a positive damage, by making the soils compact and hard to work. In the former case, the soils had the characteristics appertaining to a clay; in the latter to a sand. It is evident that before liming, a soil should be properly studied and tested. Calcium carbonate, on the contrary, would not have any such decided results. Its effects are more gradual, and perhaps more permanent.

Hopkins[8] states that a soil tends to become compact and hard with long continued use of land-plaster. He suggests that it may convert more or less of the supposedly difficultly available iron phosphate into the more readily available tricalcic phosphate, as indicated by the following equation:

$$2\ FePO_4+3CaSO_4=Ca_3\ (PO_4)_2+Fe_2\ (SO_4)_3$$

This possibility is of great local importance, since our soils, while showing a considerable amount of phosphoric acid, contain it principally as insoluble iron and aluminum salts. The statement is not to be accepted positively, however, since the results of many investigators on the action of lime compounds on soil phosphates show widely varying results, and likewise was not borne out by our results in this series.

It has been suggested by one writer that a good way to supply lime is as a mixture of carbonate and sulphate, where the former can correct the ill-effects of the latter. In comparing the relative values of gypsum and quicklime, Inery says: "Gypsum exhausts only the mineral, quicklime the irreplaceable organic matter of the soil." It is evident that lime in any of its forms is not a "universally applicable enricher of the soil," but must be applied and apportioned to a soil with the same care and judgment that is given to commercial fertilizers.

SERIES B.

Each of the lysimeters in this series was supplied with forty pounds of the lowland soil, which measured 1000 cubic inches. An acre-foot would therefore weigh 3,010,867 pounds, or in round numbers 3,000,000 pounds. Fertilizing material was added at a rate corresponding to 100 pounds of nitrogen, phosphoric acid and potash per acre, respectively. The nitrogen was supplied as ammonium sulphate; phosphoric acid as double superphosphate; and potash as sulphate, with the exception of tests 15, 23, and 24. The treatment of the several lysimeters was as follows:

13—Nothing.
14—Phosphoric acid.
15—Phosphoric acid from tri-calcic phosphate
16—Potash.
17—Nitrogen.
18—Phosphoric acid and potash.
19—Nitrogen and phosphoric acid.
20—Nitrogen and potash.
21—Nitrogen, phosphoric acid, and potash.
22—Nitrogen and calcium oxide.
23—Nitrogen as nitrate of soda.
24—Nitrogen as nitrate of lime.

The calcium in 22, as caustic lime, was intimately mixed with the soil previous to its being placed in the lysimeter. The fertilizing elements were introduced after filling the lysimeters, being thoroughly incorporated with the surface three inches. On account of the dryness of the soil, seven liters of water were required for the first irrigation in order to obtain sufficient drainage water for purposes of analysis. The subsequent irrigations were made with two and a half liters. In Tables X to XVII will be found the results reported as total grams removed, and calculated to pounds per acre-foot of 3,000,000 pounds. As in series A, the small amounts of ammonia and nitrous nitrogen are included with the nitrate in the table giving pounds per acre.

TABLE X.

Nitric Nitrogen in Drainage.

GRAMS.

Irrigation Number.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
1......	.1860	.1839	.1841	.1890	.1922	.1814	.1889	.1810	.1461	.1750	.1892	.1644
2......	.0624	.0586	.0832	.0928	.1057	.0646	.0882	.1111	.0841	.0933	.1646	.2130
3......	.0196	.0581	.0715	.0508	.0851	.0570	.0417	.0540	.0733	.0556	.1122	.1075
4......	.0140	.0422	.0389	.0159	.0458	.0214	.0269	.0457	.0547	.0291	.0355	.0247
5......	.0156	.0582	.0478	.0178	.0612	.0186	.0500	.0609	.0759	.0494	.0274	.0186
6......	.0170	.0637	.0335	.0246	.0729	.0229	.0842	.0810	.0842	.0274	.0249	.0194
7......	.0125	.0383	.0470	.0189	.0533	.0160	.0615	.0543	.0479	.0117	.0151	.0180
8......	.0143	.0639	.0495	.0261	.0490	.0212	.0463	.0502	.0329	.0118	.0179	.0169
9......	.0170	.0516	.0439	.0290	.0416	.0235	.0383	.0475	.0280	.0119	.0219	.0228
10......	.0173	.0591	.0445	.0361	.0420	.0213	.0345	.0506	.0341	.0157	.0239	.0275
Total...	.3757	.6776	.6439	.5010	.7488	.4479	.6605	.7363	.6612	.4809	.6326	.6328

TABLE XI.

Total Minerals in Drainage.

GRAMS.

Irrigation No.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
1....	3.6807	3.9655	3.6920	3.2609	3.3234	3.5195	3.4067	3.5872	3.0126	3.3118	3.6110	3.024
2....	2.6019	3.5010	4.2136	3.9849	3.9058	3.8726	4.2778	4.4306	5.1325	5.0193	5.1340	4.596
3....	2.3290	2.4186	3.0096	2.7650	3.3051	3.2629	2.3736	2.7589	2.8692	2.9072	3.4847	3.314
4....	1.5932	1.5606	1.6876	1.6216	2.0303	1.9003	1.7856	2.1714	2.1314	2.1173	1.6599	1.490
5....	1.1854	1.3608	1.5272	1.4673	1.8758	1.3507	1.8819	2.1623	2.1268	1.9446	1.4215	1.258
6....	1.3032	1.5120	1.8473	1.6465	2.0738	2.0111	2.3570	2.5714	2.6424	2.1620	1.5804	1.585
7....	1.0608	1.2586	1.5716	1.4007	1.7963	1.6139	1.7903	1.9716	1.9782	1.5345	1.1534	1.180
8....	1.0787	1.1295	1.3464	1.2277	1.5600	1.4765	1.4989	1.5930	1.6249	1.4056	1.1519	1.064
9....	.9996	1.1638	1.3761	1.2208	1.5007	1.5338	1.4689	1.5815	1.6147	1.4127	1.0980	1.194
10....	.9580	1.5289	2.0634	1.1781	1.3812	1.3766	1.2768	1.4229	1.3909	1.2442	1.0414	1.092
Total.	16.7905	19.3993	22.3348	19.7735	22.7524	21.9179	22.1175	24.2508	24.5236	23.0592	21.3362	19.800

TABLE XII.

Calcium Oxide in Drainage.

GRAMS.

Irrigation Number.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
1......	.4825	.5653	.6080	.4623	.4554	.5087	.4455	.4379	.3927	.4592	.4606	.3801
2......	.2538	.3510	.3670	.3790	.3920	.2894	.4150	.4446	.4128	.3836	.3587	.3927
3......	.2686	.2689	.3731	.3362	.3692	.3678	.2832	.3474	.3416	.3739	.3801	.3581
4......	.2003	.1637	.2132	.2017	.2035	.2015	.2046	.2710	.2526	.2837	.2082	.1613
5......	.1404	.1310	.1902	.1729	.2111	.1792	.2035	.2546	.2457	.2509	.1514	.1292
6......	.1593	.1628	.2524	.2029	.2555	.2778	.2745	.3133	.3204	.2907	.1800	.1701
7......	.1312	.1318	.2010	.1674	.2119	.2233	.2067	.2449	.2433	.2000	.1168	.1296
8......	.1148	.1170	.1805	.1523	.1936	.2142	.1736	.2025	.2096	.1856	.1400	.1181
9......	.1226	.1255	.1881	.1536	.1893	.2201	.1830	.2071	.2140	.1904	.1304	.1378
10......	.1221	.1245	.1876	.1530	.1806	.2061	.1646	.1921	.1876	.1720	.1246	.1287
Total..	1.9956	2.1415	2.7611	2.3813	2.6621	2.6881	2.5542	2.9154	2.8203	2.7900	2.2508	2.1057

TABLE XIII.

Potash in Drainage.

GRAMS.

Irrigation Number.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
1......	.0841	.0579	.0554	.0479	.0495	.0545	.0438	.0469	.0393	.0398	.0495	.0373
2......	.0599	.0460	.0593	.0517	.0588	.0542	.0641	.0679	.0716	.0589	.0745	.0785
3......	.0568	.0410	.0516	.0475	.0556	.0589	.0471	.0514	.0564	.0644	.0544	.0514
4......	.0473	.0337	.0414	.0377	.0417	.0448	.0396	.0638	.0493	.0496	.0401	.0359
5......	.0385	.0291	.0420	.0409	.0601	.0377	.0399	.0461	.0506	.0555	.0352	.0297
6......	.0459	.0389	.0489	.0445	.0556	.0595	.0660	.0725	.0640	.0595	.0491	.0438
7......	.0395	.0425	.0444	.0438	.0543	.0617	.0613	.0805	.0895	.0579	.0397	.0367
8......	.0340	.0272	.0371	.0290	.0499	.0477	.0427	.0476	.0484	.0462	.0343	.0337
9......	.0392	.0301	.0366	.0325	.0498	.0483	.0520	.0590	.0463	.0474	.0346	.0375
10......	.0384	.0370	.0325	.0320	.0483	.0443	.0410	.0425	.0421	.0371	.0332	.0326
Total...	.4836	.3834	.4492	.4075	.5236	.5116	.4975	.5782	.5575	.5163	.4446	.4171

TABLE XIV.

Nitric Nitrogen in Drainage.

Pounds per Acre-Foot of 3,000,000 Pounds.

Irrigation Number.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
1......	30.7	30.7	30.5	31.3	31.9	30.0	31.2	30.0	24.2	29.0	31.3	27.2
2......	10.4	9.7	13.8	15.4	17.5	10.7	14.6	18.4	13.9	15.5	27.7	35.2
3......	3.3	9.6	11.8	8.4	14.1	9.4	6.9	9.0	12.1	9.2	18.6	17.8
4......	2.4	7.1	6.5	2.7	7.6	3.6	4.5	7.6	9.1	4.8	5.9	4.1
5......	2.6	9.7	8.0	3.0	10.2	3.1	8.4	10.1	12.6	8.3	4.6	3.1
6......	3.0	10.5	5.6	4.1	12.1	3.8	14.0	13.4	14.0	4.6	4.2	3.3
7......	2.1	6.4	7.8	3.2	8.9	2.7	10.2	9.0	8.0	2.0	2.5	3.0
8......	2.4	10.4	8.2	4.4	8.1	3.5	7.7	8.3	5.5	2.0	3.0	2.8
9......	2.8	8.6	7.3	4.8	6.6	3.9	6.3	7.9	4.8	2.1	3.6	3.8
10......	2.9	9.8	7.4	6.0	7.0	3.5	5.7	8.4	5.7	2.6	4.0	4.6
Total...	62.6	112.5	106.9	83.3	124.0	74.2	109.5	122.1	109.9	80.1	105.4	104.9

TABLE XV.

Total Minerals in Drainage.

Pounds per Acre-Foot of 3,000,000 Pounds.

Irrigation Number	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
1......	608.6	655.7	610.4	539.2	549.5	581.9	563.3	593.1	498.1	547.6	597.1	500.0
2......	430.2	578.9	696.7	658.9	645.8	640.3	707.3	732.6	848.6	829.9	848.9	760.0
3......	385.1	399.9	497.6	457.2	546.5	539.5	392.5	456.2	474.4	480.7	576.2	548.1
4......	263.4	258.0	279.1	268.1	335.7	314.2	295.2	359.0	352.4	350.1	274.5	246.4
5......	196.0	225.0	252.5	242.6	310.2	223.3	311.2	357.5	351.7	321.5	235.0	208.0
6......	215.5	250.0	305.4	272.2	342.9	332.5	389.7	425.2	436.9	357.5	261.3	262.2
7......	175.4	208.1	259.9	231.6	297.0	266.9	296.0	326.0	327.1	253.7	190.7	195.1
8......	178.4	186.8	222.6	203.0	257.9	244.1	247.8	263.4	268.7	232.4	190.5	176.0
9......	165.3	192.4	227.5	201.9	248.1	253.6	242.9	261.5	267.0	233.6	181.5	197.5
10......	158.4	252.8	341.2	194.8	228.4	227.7	211.1	235.3	230.0	205.7	172.2	180.6
Total..	2776.3	3207.6	3692.9	3269.5	3762.0	3624.0	3657.0	4009.8	4054.9	3812.7	3527.9	3273.9

TABLE XVI.

Calcium Oxide in Drainage.

Pounds per Acre-Foot of 3,000,000 Pounds.

Irrigation Number.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
1......	79.8	93.4	100.5	76.4	75.3	84.1	73.7	72.4	64.9	75.9	76.2	62.9
2......	42.0	58.0	60.7	62.7	64.8	47.9	68.6	73.5	68.3	63.4	59.3	64.9
3......	44.4	44.5	61.7	55.6	61.1	60.8	46.8	57.5	56.5	61.8	62.9	59.2
4......	33.1	27.1	35.3	33.4	33.6	33.3	33.9	44.8	41.8	46.9	34.4	26.7
5......	23.2	21.7	31.4	28.6	34.9	29.6	33.6	42.1	40.6	41.5	25.0	21.4
6......	26.4	26.9	41.7	33.5	42.2	45.9	45.4	51.8	53.0	48.1	29.8	28.1
7......	21.7	21.8	33.2	27.7	35.1	36.9	34.0	40.5	40.2	33.1	19.3	21.4
8......	19.0	19.3	29.9	25.2	32.0	35.4	28.7	33.5	34.7	30.7	23.1	19.6
9......	20.3	20.8	31.1	25.4	31.3	36.4	30.3	34.2	35.4	31.5	21.6	22.8
10......	20.2	20.6	31.0	25.3	29.9	34.1	27.2	31.8	31.0	28.4	20.6	21.3
Total...	330.1	354.1	456.5	393.8	440.2	444.4	422.2	482.1	466.4	461.3	372.2	348.3

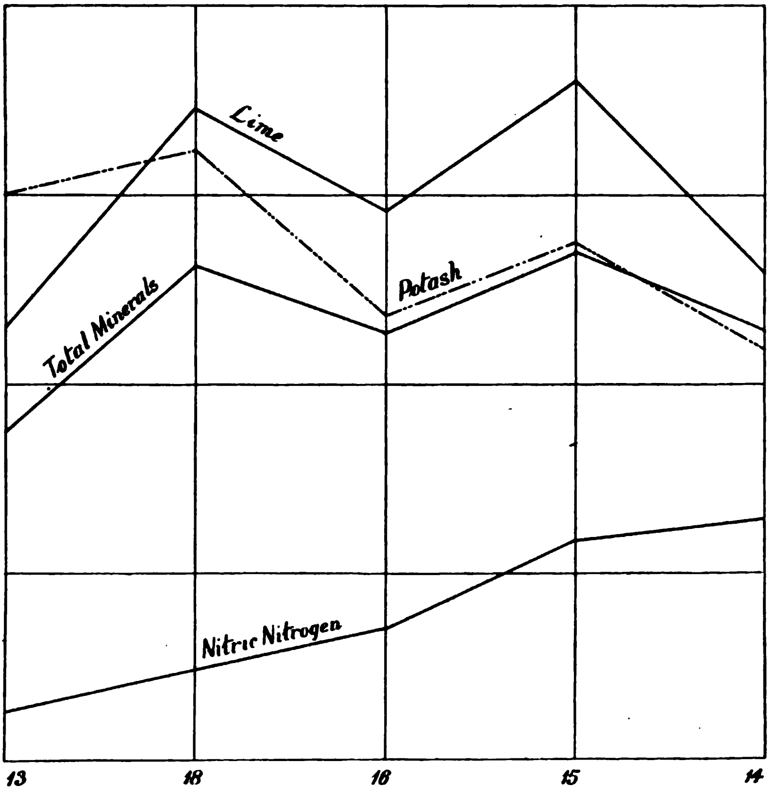
TABLE XVII.

Potash in Drainage.

Pounds per Acre-Foot of 3,000,000 Pounds.

Irrigation Number.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
1......	13.9	9.6	9.2	7.9	8.2	9.0	7.2	7.8	6.5	6.6	8.2	6.1
2......	9.9	7.6	9.8	8.5	9.7	9.0	10.6	11.2	11.8	9.7	12.3	13.0
3......	9.4	6.8	8.5	7.9	9.2	9.7	7.9	8.5	9.3	10.7	8.9	8.5
4......	7.8	5.6	6.8	6.2	6.9	7.4	6.6	10.5	8.2	8.2	6.6	6.0
5......	6.4	4.8	6.9	6.8	9.9	6.2	6.6	7.6	8.4	9.2	5.8	4.9
6......	7.6	6.4	8.1	7.4	9.2	9.8	10.9	12.0	10.6	9.8	8.1	7.3
7......	6.5	7.0	7.4	7.2	9.0	10.2	10.1	13.3	14.8	9.6	6.6	6.1
8......	5.6	4.5	6.1	4.8	8.2	7.9	7.1	7.9	8.0	7.6	5.7	5.6
9......	6.5	5.0	6.0	5.4	8.2	8.0	8.6	9.8	7.6	7.8	5.7	6.2
10......	6.4	6.1	5.4	5.3	8.0	7.3	6.8	7.0	7.0	6.1	5.5	5.4
Total...	80.0	63.4	74.2	67.4	86.5	84.5	82.4	95.6	92.2	85.3	73.4	69.1

Chart 2.



It is apparent that in this series we are dealing with a soil extremely high in soluble calcium compounds. In the previous set of lysimeter experiments reported by this station, 164 pounds of dry soil, after twenty-one irrigations, gave 3.3 grams lime in the drainage. With the soil of our present experiment, the check test, containing thirty-eight pounds of dry soil, gave almost 2 grams of lime after ten irrigations. It is probably due to the original alkalinity of the soil and the presence of sufficient amounts of soluble lime salts that the further addition of lime depressed the amount of nitrate nitrogen found from sulphate of ammonia from 124 pounds in test 17 to 80.1 pounds in test 22. The excessive alkalinity presented a condition unfavorable for the normal functioning of the nitrifying organisms. Such a condition is usually associated with excessive acidity of soil; an excess in the opposite direction is equally unfavorable. Warrington, as has already been mentioned, found that limewater is a much stronger alkali than the nitric ferments can bear, and in this case we probably had a soil solution which, while not as strongly alkaline as limewater, was nevertheless of sufficient alkalinity to inhibit normal nitrification.

The effects of the fertilizing elements on the soil nitrogen are shown in tests 13, 14, 15, 16, and 18, and are illustrated in Chart 2. The best result, in respect of nitrification, was obtained in test 14, where superphosphate was used; the poorest in 18, where superphosphate and potash were applied together. Phosphoric acid, as tri-calcic phosphate, was but slightly inferior in its effects than when applied as the acid salt; and potash alone was slightly better than potash along with acid-phosphate. The increase in nitric nitrogen was accompanied by changes in the lime and potash as follows:

Test 18—Large rise in lime; small rise in potash.
Test 16—Rise in lime; large drop in potash.
Test 15—Large rise in lime; slight drop in potash.
Test 14—Slight rise in lime; large drop in potash.

The chemical transformations occurring in any soil are naturally very involved, and apparently contradictory and unexplainable results are often obtained. Thus, working with a soil excessively rich in soluble lime, the best results might be expected where the increase in soluble lime is the least. The poorest result was obtained in test 18, where a large increase of lime occurred; but this was true also of test 15, yet 107 pounds of nitric nitrogen were produced here, while test 18 yielded only 74 pounds. The explanation of this must be sought in the form of calcium leached out into the drainage waters and thus present in the soil water. Thus, in test 18, along with 100 pounds of potash, added as sulphate, there were added 85 pounds of sulphur trioxide. Of the 100 pounds of the potash added, only five pounds were found in the drainage waters; it is therefore reasonable to conclude that of the lime liberated a large proportion was drained as gypsum. The experiments at this station in 1906 showed that gypsum had an unfavorable effect on nitrification in lowland soil abundantly supplied with lime. A corresponding effect is one explanation of this drop in nitrification in the present instance. In test 15, the lime recovered in drainage was not in the form of sulphate, at least not to an extent greater than in the other experiments, since no sulphuric acid was added. It may be explained by (1) the replacement of the lime by iron and aluminum in the soil, and its drainage as silicate; or (2) in the first series it was noted that increased nitrate production was generally accompanied by an increase of calcium in drainage. The tri-calcic phosphate acted as stimulant to the nitrification, whence it follows that more lime was withdrawn from the soil in the form of soluble calcium nitrate.

Where potash alone was added, the lime in the drainage increased over the check test 63 pounds, while the potash decreased 13 pounds. There has apparently been a reaction here counter to that occurring when gypsum is added; the potassium as sulphate released the lime from its insoluble combination, forming insoluble potassium compounds (i. e., the potassium was fixed), and releasing the calcium as soluble sulphate. Thus the least increase in nitrification is found in those tests where the presence of soluble calcium sulphate can be explained.

Where acid phosphate was added, a different set of reactions followed. The soluble phosphoric acid was, as in all tests, entirely fixed in the soil. A combination must have been effected between it and the calcium, iron, and aluminum compounds. Since the soil was quite alkaline and contained considerable soluble lime, it is most probable that the combination was largely with calcium; and not at all unlikely that the reduction of alkalinity favored the transformation of the soil nitrogen, as reflected in the large amount of nitric nitrogen found in the drainage. There were but 24 pounds more of lime found in the drainage than in the check test, and 102 pounds less than in test 15, which received its phosphoric acid as tri-calcic phosphate. This last is partly explained by the fact that in applying 100 pounds of phosphoric acid as tri-calcic prosphate, 118 pounds of calcium oxide were also added; where the phosphoric acid came from double superphosphate, only 40 pounds of calcium oxide were added.

TESTS WITH AMMONIUM SULPHATE.

In the tests where ammonium sulphate was added, quite different conditions obtain than in the preceding. In supplying 100 pounds of nitrogen in this form, 285 pounds of sulphuric oxide were also added. In a soil rich in free lime, the sulphuric oxide released from its combination with the ammonia following the conversion of the latter into nitric nitrogen, or previously by a chemical reaction, would very naturally combine with the lime to form the soluble calcium sulphate. The maximum nitrogen recovered as nitrate was 124 pounds, or 61.4 pounds more than in check test 13. On this basis, 61.4 per cent of the ammonium nitrogen was converted into nitric nitrogen during the time of the experiment. In the same length of time, lysimeter tests in 1906 gave 62.5 per cent of of the nitrogen added as ammonia. The action of the two soils is therefore fairly comparable. The soils in the experiments of 1906 were unfavorably effected as regards nitrification by gypsum. In the present soil, on adding potash to the soil, 42 pounds more of lime than in test 17 were found in the drainage water, and a slight drop in the nitric nitrogen is observed. Where superphosphate was added, either with or without the potash, there resulted a loss of 14 to 14.5 pounds of nitric nitrogen when compared with test 17, whilst the lime and potash in the drainage in the superphosphate test 19 are lower than in check test 17. This latter result compares with the relationship holding in the tests not receiving sulphate of ammonia, an explanation of which was attempted while dis-

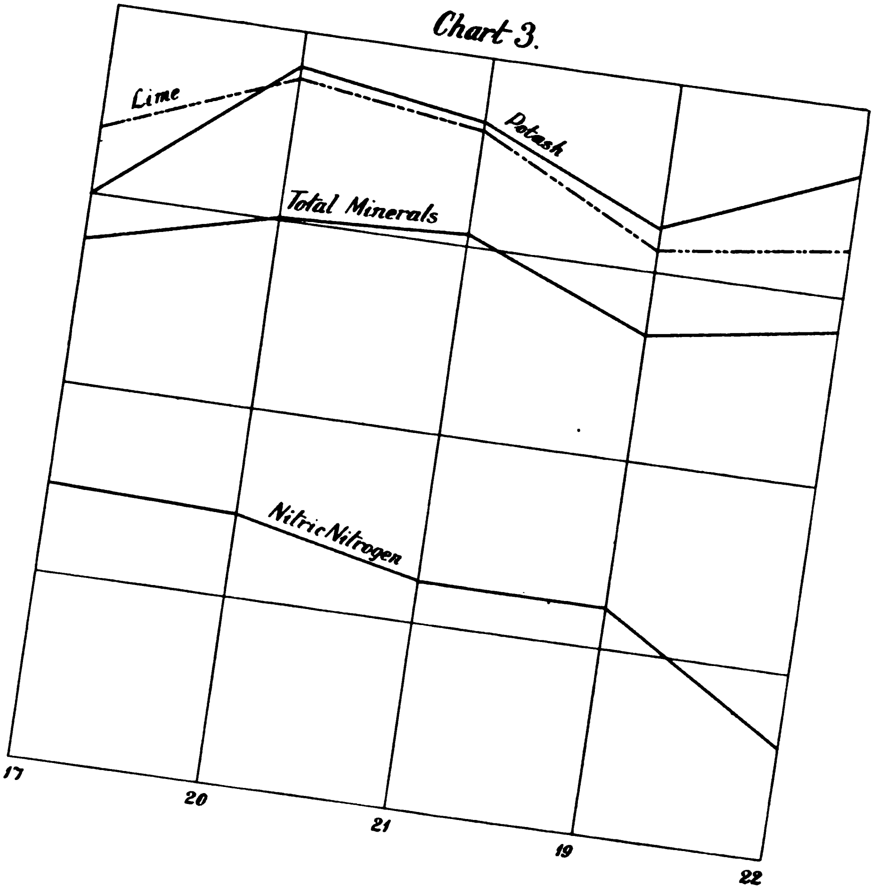


Chart 3.
Lime
Potash
Total Minerals
Nitric Nitrogen
17
20
21
19
22

cussing the results. There, however, the superphosphate exerted a most beneficial influence; in these latter tests its influence was quite in the contrary direction. A possible explanation is that of the effect of superphosphate on the ammonifying and nitrifying organisms in soil. In a series of bio-chemical tests reported by this station in 1910,[9] the soil treated being a typical lowland soil, it was found that soil treated with superphosphate accelerated ammonification in peptone solution, and depressed nitrification in a solution of ammonium sulphate. Similarly, in the lysimeter test to which ammonium sulphate and superphosphate were added, the rate of nitrification and, as a consequence, the total amount of nitric nitrogen found at the expiration of the test, were lowered.

The action of added caustic lime on nitrification of ammonium sulphate in this soil has already been commented on. Nitrification was considerably depressed, due entirely, we believe, to the excessive alkalinity of the soil solution. The results of these tests are shown graphically in Chart 3.

TESTS WITH NITRATES.

Nitrate of soda and nitrate of lime give about the same amounts of nitric nitrogen in the drainage, both being inferior to sulphate of ammonium in this respect. The amount of lime in the drainage, as in previous experiments at this station, was also less in the nitrate than in the sulphate of ammonia test. The rate at which nitric nitrogen was present in solution also showed the same relative differences as before. Whereas in test 17 with sulphate of ammonia, 65.6 per cent of the total nitrogen recovered was obtained after the first half of the duration of the experiment, the nitrate tests 23 and 24, yielded 83.5 per cent of the total. The nitrate forms had then the advantage in immediate availability, but the ammonia nitrogen supplied a greater sum total and more gradually. Twenty weeks after the application of the fertilizers, there was found in test 17, 7 pounds of nitric nitrogen in the drainage water; tests 23 and 24, fertilized with sodium nitrate and calcium nitrate, yielded 4 and 4.6 pounds, respectively. Indeed, after the third irrigation, or six weeks from the start, the ammonia fertilization was giving more nitric nitrogen than did either of the nitrate tests.

GENERAL CONCLUSIONS.

The results of the tests of series B, while showing the effects of the respective treatments on the production of nitric nitrogen, do not absolutely indicate the treatment that should be accorded a land of similar composition under cane. The results recorded here report the effects on the transformation of the soil nitrogen; under crop conditions, other considerations, such as the supplying of mineral nutriment for the growing crop, the influence on the texture and water-holding capacity of the soil on which a crop is growing, the effect of the fertilizers on insect and parasitic life, etc., present new complications, which can be solved only by field tests *in situ*. However, of the nutrients necessary for cane-crop growth, nitrogen is the most essential for gains in yield, and any method of treatment, such as in test 22, from which indubitably harmful conditions for nitrification accrued, may be very safely accepted as one to be avoided. The best results as regards quantity of nitric nitrogen produced was obtained in test 17, where only sulphate of ammonia was applied. Yet this method of treatment is not advised in actual practice, since it would work towards the depletion of the soil, both in drainage waters and crop, of the other important elements, such as potassium and phosphoric acid. These elements should continue to form a part of the usual applications to the soil, in order to conserve its fertility. It is a matter of regret that the soil used in this second series had been treated with lime a short time previous to being sent to us, and therefore did not represent a more nearly typical normal soil. However, since the practice of liming is very general, the results as obtained are both interesting and instructive, showing the transformation of nitrogen into nitric nitrogen in a soil to which lime had been applied, probably, as in this case, to an excessive extent.

SUMMARY.

(A) Working on an upland soil, rich in organic matter, poor in soluble lime and potash, and acid to litmus:

(1) Calcium additions as oxide, carbonate or sulphate, increase the nitrification of the soil nitrogen or nitrogen added as sulphate of ammonia.

(2) Calcium additions as oxide, carbonate or sulphate, increase the amounts of lime and potash soluble in water and recovered in the drainage.

(3) Calcium sulphate was more effective in all three respects than calcium oxide or carbonate.

(4) The acidity of the soil did not seem the controlling factor as regards nitrification; the water-soluble calcium seemed of greater significance.

(5) Fertilizing with water-soluble phosphoric acid and sulphate of potassium produced a slight increase in the nitrification of ammonium sulphate.

(6) Any increase in nitrification was generally accompanied by an increase in lime in the drainage.

(B) Working on a lowland soil, containing a moderate amount of organic matter, rich in soluble calcium, and alkaline to litmus:

(1) Additions of fertilizing materials, as double superphosphate, tri-calcic phosphate and sulphate of potassium, increased the amount of nitric nitrogen formed from the soil nitrogen.

(2) The best results in this respect followed the use of double superphosphate or tri-calcic phosphate.

(3) A decrease in nitrification resulted from the use of potash and phosphoric fertilizers in lysimeters to which nitrogen as ammonium sulphate was added.

(4) The greatest depression in this respect followed the addition of double superphosphate.

(5) Liming with caustic lime depressed greatly the amount of nitric nitrogen obtained from sulphate of ammonia.

(6) No difference was observed between the nitric nitrogen in the drainage obtained from equal applications of nitrogen as sodium nitrate and calcium nitrate.

(7) Both nitrate fertilizations yielded less nitric nitrogen in the drainage than was obtained from an equal amount of nitrogen as ammonium sulphate.

(8) Less lime was found in the drainage from the nitrate applications than from the ammonium sulphate application.

(9) There was no relationship between the lime in drainage and extent of nitrification.

In conclusion the writer desires to express his obligations to the Director, Mr. C. F. Eckart, for assistance in planning the experiments; and to Mr. A. E. Jordan, assistant chemist, who performed a large proportion of the analyses.

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AGRICULTURAL AND CHEMICAL SERIES BULLETIN NO. 38

REPORT OF WORK
OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

The Milling of Cane Considered in Relation to the Volume Occupied by the Fiber

BY NOEL DEERR.

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LETTER OF TRANSMITTAL.

To the Experiment Station Committee of the
Hawaiian Sugar Planters' Association,
Honolulu, T. H.

Dear Sirs:—I herewith submit for publication as Bulletin No. 38, of the Agricultural and Chemical Series, an article by Mr. Noël Deerr, Sugar Technologist, entitled: "The Milling of Cane Considered in Relation to the Volume Occupied by the Fiber."

Yours very truly,

C. F. Eckart,
Director.

Honolulu, January 22, 1912.

THE MILLING OF CANE CONSIDERED IN RELATION TO THE VOLUME OCCUPIED BY THE FIBER.

By Noël Deerr.

PART I.

THE EXPERIMENTAL STUDY OF THE BEHAVIOR OF CANE FIBER UNDER PRESSURE.

The almost universally accepted method of extracting juice from the sugar cane consists in subjecting the cane to heavy pressure between revolving rollers; the machinery used for the purpose has become highly standardized but as far as the writer is aware there are on record no experiments dealing with the behavior of cane fiber under pressure; it was thought that possibly information of value might be obtained and applied to existing problems from a study of the results of pressures on cane fiber under such conditions that the weight of juice expressed and volume of fiber corresponding to definite pressures could be measured. An account of the experiments made and a discussion of their bearing on the process of milling is given in the following pages.

Apparatus employed. The tests were made in four machines; the greater number were conducted in two machines belonging to the College of Hawaii; one a Riehlé testing machine designed for use either in tension or compression and of a capacity of 150,000 lbs.; the other an Olsen hydraulic compression machine designed especially for compression tests of cement cubes; it was of a capacity of 40,000 lbs. These machines were very kindly placed at my disposal by Dr. Gilmore, President, and Dr. Young, Professor of Engineering at the College of Hawaii. My thanks are also due to Dr. Young for giving much time to superintending the operation of the Riehlé machine, and for much help in designing the apparatus and in discussing the results obtained.

In Fig. 1 is shown a view of the Riehlé machine with the apparatus installed; Fig. 2 shows a similar view of the Olsen machine; Fig. 3 gives a view of the special apparatus used in connection with the Riehlé machine, and in Fig. 4 is shown in section a view of the pressure pot or receptacle for holding the material under pressure, used with the Olsen machine. That used with the Riehlé machine was similar but larger.

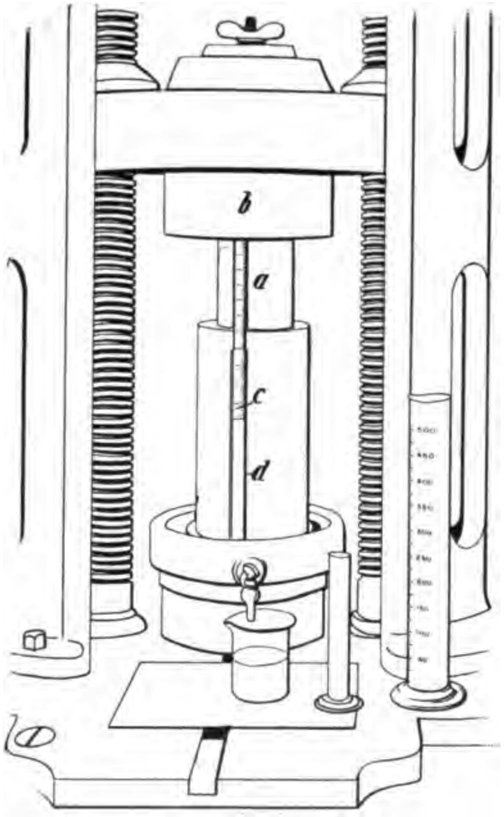

Fig. 1

The pressure pot used in conjunction with the Olsen machine consisted of a steel cylinder 7.39″ high and 3.28″ in internal diameter; the walls of the pot were .4″ thick; the bottom of the pot consisted of a removable steel disc .6″ thick and fitting closely to the pot; twenty-nine holes .125″ in diameter and connected to each other by channels were drilled in this disc; on the bottom of the pressure pot eight channels were also formed so that juice expressed from the material under pressure could escape freely. The pressure pot stood on a steel saucer 5.5″ internal diameter and which served to contain the expressed juice; an annular channel .25″ wide and deep and 5″ in diameter was made in the saucer; in this channel was a hole .25″ in diameter which could be closed by a rubber stopper and whence the expressed juice could be drawn off and measured in graduated vessels. The pressure pot used in connection with the Riehlé machine was 10″ high and 4″ in internal

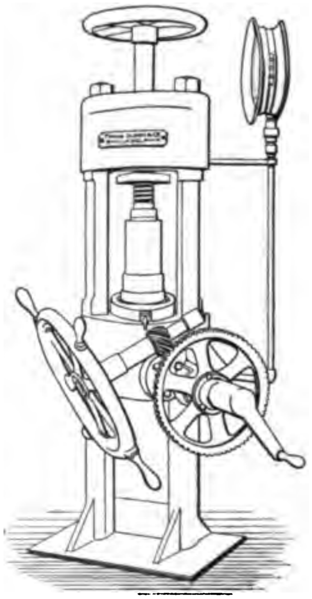

Fig. 2

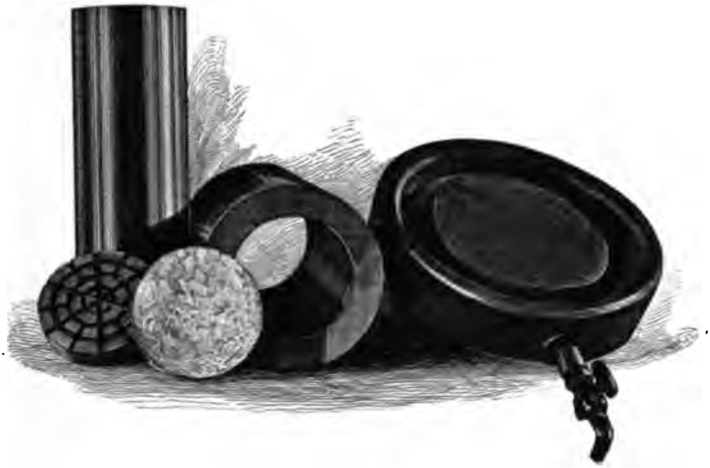

FIG. 3

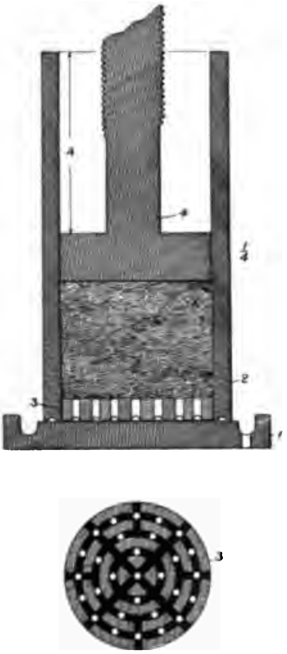

FIG. 4

diameter; a removable and perforated disc formed the bottom and a saucer similar to but larger than the one described above served to catch expressed juice; a steel plunger 12″ long and 4″ diameter was used to transmit pressure from the head of the testing machine to the material contained in the pot.

When using the Olsen machine the pot filled with the material to be examined was placed in the position shown in Fig. 2; the plunger was then screwed down on to the surface of the material by means of the wheel; a gauge pressure of 4500 lbs. could be obtained by this means; the hydraulic pressure was then applied through the ram, operated by the gear seen at the right of the cut; measurment of the height and consequently the volume of the compressed material was obtained by measuring the distance from the top of the plunger to the top of the pot, that is to say the distance *xx*, Fig. 5; the depth of the plunger was

.98″ so that the height of the column of compressed material was 7.30 — (xx + .98) inches. In using the Riehlé machine the pot filled with material to be examined was placed in the position shown in Fig. 1; the plunger *a* was allowed to fall down on to the surface of the material, pressure being applied by screwing down the head *b* on to the plunger; measurement of the height of the material under compression was made thus; a scale *c* graduated to hundredths of an inch slid freely in the holder *d*; a fixed mark on the holder was made 1″ below the top of the pressure pot; as the upper head *e* of the machine descended it pushed down the scale and readings were made opposite the fixed mark on the holder; as the plunger was two inches longer than the pot the reading on the scale diminished by three inches gave the height of the column of compressed material. The third machine used, and only for a few preliminary experiments, was an hydraulic press employed chiefly for forcing off wheels from the axles of cane cars. The apparatus which was improvised from material at hand consisted (Fig. 5) of an iron pot 4 3/16″ in diameter and 9 inches long; *bb* is a solid iron cylinder closely fitting into *aa* and serving to transmit the pressure from the plunger of the ram *cc*, which is 5 inches in diameter. The pot was filled with bagasse taken as it left the back roller of a mill, lightly pressed and placed in position between the back stop of the press and the ram. The plunger *bb* was then inserted into the pot and the press pumped up until the plunger and ram met. The pressure was obtained by pumping and was kept steady at 2, 5, 10, 20, 40 tons per square inch of rain as shown by the gauge, whence was calculated the pressure in pounds per square inch

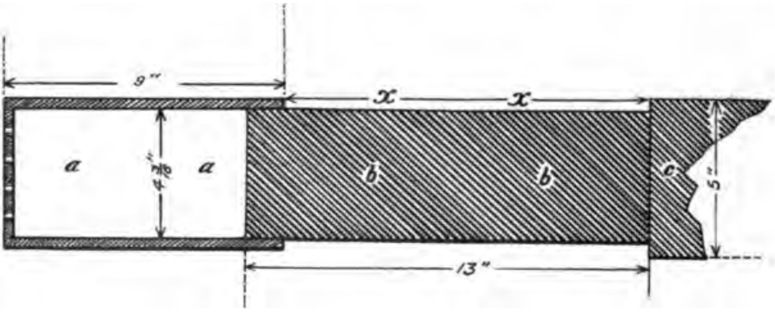

FIG. 5

on the surface of the bagasse in the pot. The volume occupied by the bagasse was obtained by measuring the distance *xx* from the end of the pot up to the face of the ram.

The fourth piece of apparatus used was made especially to elaborate certain points which appeared on examination of the results obtained from the experiments as originally planned. It consisted, Fig. 6 of a hollow brass cylinder *a* .25″ in internal diameter and 3.006 inches long; this cylinder was screwed ¾″ standard gas thread at both ends; on the upper end a circular plate *b* five inches in diameter was screwed down on to a projecting collar; the position of this plate was in this way fixed and it served as a reference position. The base of the apparatus was a circular plate of iron *cc* five inches in diameter and .75″ high into which was screwed the hollow brass cylinder *a;* the recess into which this fitted penetrated only .5″ into the plate; a small hole 1/64″ diameter was drilled through the remaining .25″ of metal so as to serve for the escape of any juice which might be pressed out of the material. The plunger *d* by means of which pressure was transmitted to the material contained in the hollow cylinder was of steel and was of diameter .249″; the plunger was 3.010 inches long and was screwed ¾″ standard gas thread at one end; on this end was screwed a five inch circular plate *ce* similar in every respect to the one serving as the base of the apparatus: as the screwed recess did not pass completely through the plate it could always be screwed down to the same position; measurement of the distance between the plates *b* and *e* gave a measurement of the length of the plunger within the cylinder *a* and consequently of the height and volume of the material therein contained; this measurement was made to .001″ by means of a micrometer caliper square.* Pressure was obtained on the material in the cylinder by means of lead weights placed on top of the plate; the weights of 100 lbs. and upwards were cast 8″ in diameter, the smaller ones being made 4″; as the area of the surface under pressure was .04909 sq. in. a weight of 1 lb. on the plunger corresponded to a pressure of

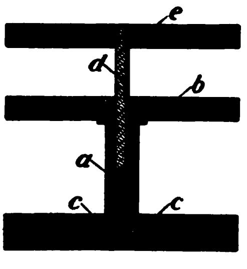

FIG 6

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* A more elegant method of measurement would have been by means of a sliding scale and vernier, the vernier being fixed on the side of the cylinder *aa* and the sliding scale moving downwards with the downward motion of the plunger; means were not available locally to make this.

20.37 lbs. per sq. in. on the material within the cylinder. This apparatus with weights in position is shown in Fig. 7.

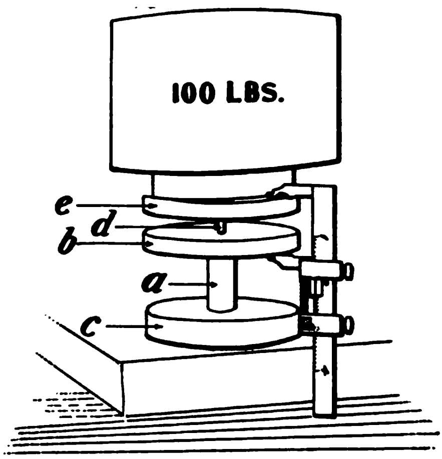

Fig. 7

Method of Making a Test. The method employed in making a test was the same when using either machine. A weighed quantity of chopped cane or bagasse was placed in the pressure pot. A gradually increasing pressure was applied and at intervals corresponding to observed pressures the juice expressed was collected in graduated vessels, the volume of residue remaining in the pressure pot being measured at the same time. At the conclusion of a test the wad of compressed material remaining in the pot was removed and weighed. It was found that the weight of juice expressed plus the residue fell short of the original weight of material by about .005 lb. due to juice remaining in the saucer which could not be collected; in working out the results this shortage was added to all the measurements of juice made.

Connection between quantity of material used in pressure pot and tonnage of cane milled hourly.

In planning the experiments to be tried it was necessary that the quantity of bagasse or of chopped cane contained in the pressure pot should, in regard to the area over which the pressure was distributed, bear some relation to the amount of cane milled in actual practice. A relationship serving to indicate what quantities of material to use was obtained on the following argument. A 78″ mill worked at a surface speed of 25 feet per minute describes 23400 sq. ins. in one minute; in one hour let 100,000 lbs. cane containing 12% fiber be milled, or 12,000 lbs. fiber per hour, that is to say 200 lbs. of fiber per minute correspond to 23,400 sq. in. of roller surface. The surface under pressure in the pot used with the Olsen machine was 8.43 sq. in. so that the quantity of material used to correspond with the milling of 100,000 lbs. of cane with 12% of fiber per hour would contain $\frac{8.43 \times 200}{23,400}$ = .072 lb. fiber.

In the results tabulated in the following pages the quantities of material used are referred on a fiber basis to so many tons of cane per hour the basis of calculation being as described above, that is to say with reference to a 78″ roller moving at 25 feet per minute and to cane containing 12% of fiber.

Pressure at Which Juice Flowed from Bagasse. It was thought in planning these experiments that observations of the pressure at which juice began to flow from bagasse sampled as it left one of the mills of a train would give an indication of the pressure to which bagasse had been subjected in its passage. Accordingly bagasse was placed in the pressure pot and subjected to a gradually increasing pressure; the pressure corresponding to the appearance of juice was noted; the results of a number of determinations are given below, the bagasse in all cases coming from mills 78″x34″.

Bagasse from Mill.	Load on Journals—Pounds.	Percentage of Fiber in Bagasse.	Pressure at which Juice flowed—Lbs. per sq. in.	Machine Used.
First	800,000	26.3	205	Wheel press
“	“	33.2	420	Olsen machine
“	“	33.2	470	“ “
“	“	33.2	530	“ “
“	“	33.2	560	“ “
Second.......	860,000	35.6	410	Wheel press
“	820,000	37.3	657	Olsen machine
“	“	37.3	870	“ “
Third	900,000	43.8	410	Wheel press
“	“	43.8	410	“ “
“	840,000	44.3	679	Olsen machine
“	“	44.3	710	“ “
“	798,000	41.0	650	“ “
Fourth.......	706,000	40.0	850	“ “
“	706,000	40.0	1100	“ “
“	706,000	40.0	1100	“ “
Fifth	856,000	44.8	1700	“ “
“	856,000	44.8	1350	“ “
“	856,000	44.8	1100	“ “

Examination of the results tabulated above show so many irregularities that no conclusion can be drawn therefrom, and the pressure at which juice begins to flow from the bagasse contained in the pressure pot is evidently only connected in the most indirect way with the pressure to which the material has been subjected, as the following calculations will show. In the case of a 34″x78″ mill let the apical angle (Fig. 8) be 82° and let a load of 840,000 lbs. be applied to the hydraulic; then the resultant pressure along the line *a c* is 840,000 cos 41° = 633,948 lbs. Suppose that the pressure to which the bagasse has been subjected is the same as that at which juice begins to flow and let this pressure be 679 lbs. per sq. in.; then the area over which the hydraulic load of 633,948 lbs. must be distributed to give this pressure is $\frac{633948}{678}$ or 920 sq. in.; the length of the strip of bagasse in the mill is 78 inches so that on this reasoning the width of the strip of bagasse would be $\frac{920}{78}$ = 11.8 inches, a result manifestly without application unless it were to show that only a very small portion of the pressure were effectively utilized.

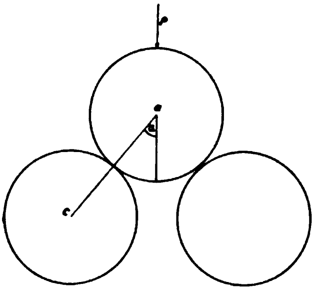

FIG. 8

The first objection that can be opposed to any connection between pressure on rollers and pressure at which juice begins to flow existing is that no account is taken of reabsorption of juice taking place after the bagasse has passed the point of maximum pressure between the rollers; further experiments showed in addition that any connection that might exist was extremely vague since it was observed that chopped cane might be pressed in the pressure pot and up to 70% of juice extracted at a pressure of 4740 lbs. per sq. in.; if this pressed cake of material were taken out, opened up and again pressed a flow of juice was obtained at a much lower pressure than that to which the material had already been subjected. Experiments made on this point showed that chopped cane which had been pressed up to a pressure of 4740 lbs. per sq. in. would on pressure a second time give a flow of juice at pressure varying from 1000 to 1500 lbs. per sq. in. The effect of repeated pressings not being without interest a series of experiments were made on this point.

Effect of repeated pressings. In the previous section it was mentioned that chopped cane when subjected to great pressure and when again pressed after removal from the pressure pot, gave a further supply of juice, the flow of juice beginning at a much lower pressure than that to which the material had already been subjected. Experiments were made along these lines as follows:

Chopped cane weighing .882 lbs. was placed in the pressure pot used in the Olsen machine; the cane used in these experiments contained 12.0% of fiber so that the .882 lbs. correspond to 147,000 lbs. of cane per hour in a 78″ mill. This weight of material was then pressed to a pressure of 4740 lbs. per sq. in.; after the juice had ceased to flow the wad of bagasse was removed from the pot and weighed; the loss in weight was taken as the amount of juice expressed. The residue was then broken up by gently rubbing between the hands, replaced in the pot and again pressed to 4740 lbs. per sq. in.; a second flow of juice took place, the amount of which was determined as before; these pressings were made in all five times and it was observed that at the fifth pressing no further flow of juice took place.

The chopped cane used was of five degrees of fineness varying from a fine meal to pieces of about ¼ inch cube; the results are given in the following table, the results with the coarsest material being tabulated at the left, thence towards the right as the degree of fineness increases:

ALL PRESSURES AT 4740 LBS PER SQ. IN.

	Juice obtained % on original subject	Total percentage obtained...	Juice obtained % on original subject	Total percentage obtained ...	Juice obtained % on original subject	Total percentage obtained ...	Juice obtained % on original subject	Total percentage obtained...	Juice obtained % on original weight	Total percentage obtained...
First pres.	58.3	58.3	59.0	59.0	62.3	62.3	64.0	64.0	64.4	64.4
Second "	8 5	66.8	8.8	67.8	8.8	71.1	9.9	73.9	12.0	76.4
Third "	5.8	72.6	6.0	74.8	3.9	75.0	4.7	78.9	2.6	79.0
Fourth "	2.8	75.4	2 4	76.2	2.0	77.0	1.6	80.2	2.0	81.0

The continual expression of juice at constant pressure can be readily understood on the idea that the solid particles form themselves into "*cells*" forming spaces occupied by juice which is not then subjected to pressure and has no tendency to be expressed. The increase in amount of juice expressed at the same pressure with rearrangement of the material is very remarkable and may, perhaps, be used as an argument of multiple pressing at lower pressures as a more effective scheme for obtaining the juice than a less number at higher pressures. In stepping, however, from experiments made in a small pot to a factory equipment considerable conservatism must be allowed and a reason is at once apparent why so great an increase in the quantity of juice expressed with multiple pressings at the same pressure would not obtain in factory conditions. In these experiments the pressure is static and the material under pressure is stationary; in a mill this pressure is a rolling one and hence the material under pressure is constantly being rearranged.

Referring to the table given above it will be seen that the same quantity of material under different conditions but under one uniform pressure afforded an expression of juice varying from a minimum of 58.3% to a maximum of 81.0%, the varying factors being fineness of material and number of pressings; these results show that there can be none but the vaguest connection between pressures and amount of juice extracted and also show the difficulty of finding a basis upon which to compare the results of different mills. In a subsequent section (page 25) are given results showing the amount of juice obtained from finely chopped cane when pressed up to a pressure of 11940 lbs. per sq. in.; the cane used in that experiment was of the same percentage of fiber and same degree of fineness as the finest in the experiment described in the present section. On referring to that experiment (page 25) it will be seen that 64.6% of juice was obtained with a pressure of 4775 lbs. per sq. in.; increasing the pressure up 11960 lbs. only gave 67.6% of juice, while a single rearrangement of the material after pressing to 4740 lbs. and again pressing afforded 76.4% of juice, while on the fourth pressing 81.0% was obtained in all. This experiment would tend to show that repeated pressings are of much more importance than a single pressing at enormously increased pressures; to have obtained 81% of juice in one pressing would have required an enormous pressure.

Effect of fineness of division on amount of juice expressed. The more finely a material is divided the greater is the total area of the surface of the pieces into which it has been divided; a finely divided material will then absorb and hold by capillary attraction a greater weight of liquid than the same weight of one which has not been so finely divided. This argument has been used in opposition to the schemes employing crushers and heavily grooved rollers which tear up and shred the cane; it was accordingly thought worth while to press under uniform conditions of pressure the same weight of material in different degrees of fineness. This experiment was performed in conjunction with that described in the immediately preceding section dealing with the effect of repeated pressings; on reference to the table on page 13 it will be seen that as the degree of fineness of the chopped cane increases so also does the amount of juice expressed; for example, where with a single pressing the coarsest material afforded 58.3% of juice, the most finely divided material gave 64.4%. It would appear then from the results of this experiment that not only is fineness of division not objectionable but that it is attended by very considerable benefit, and in addition there can be no possible question as to the utility of fine division and large surface in connection with the absorption and efficient utilization of water and dilute juices added to the maceration process.

Effect of thickness of layer of material on amount of juice expressed. Since the material under pressure in any series of these experiments was contained in the same pot varying the weight of material will also vary in direct proportion to the weight the thickness of the layer of material under pressure. One of the questions in regard to the working of milling plants which has been discussed most frequently in the past and which still remains a subject for argument is the advantages of thick and thin feeds; actually the tendency during the last fifteen years or so has been towards a greater surface speed of the rollers whereby the thickness of the layer of material under pressure is diminished, the weight of material treated however remaining the same. Conversely, if the speed of the rollers remains the same an increase in the amount of material treated would give a thicker layer of bagasse under pressure; hence experiments dealing with the amount of juice obtained with variation in the weight of material under pressure might be applied as bearing on both these problems. Accordingly the amount of juice obtained from different amounts of chopped cane and of bagasse under a constant pressure was experimentally determined. In this experiment the Olsen machine was used, the weight of chopped cane containing 12% fiber varied from .220 lb. to 1.763 lb., which in the pressure pot used with the Olson machine would (page 20) correspond to a tonnage of cane varying from 30,500 to 244,000 lbs. per hour at a surface speed of 25 feet per minute in a 78″ mill. The pressure in all cases was 4740 lbs. per sq. in. and the results obtained are as in the following table:

Weight of Cane—Lbs.	Equivalent in lbs. per hour in 78″ mill at a surface speed of 25 ft. per min.	Percentage of Juice Obtained.	
		I.	II.
1.763	244,000	63.40	62.90
1.323	184,000	65.75	63.75
.881	122,000	68.50	67.60
.440	61,000	69.50	68.70
.220	30,500	74.00	70.00

In these experiments then a decrease in the thickness of the layer of material under pressure is accompanied by an increase in the amount of juice extracted; the limits of this experiment overlap very much indeed the variation in amount of cane which would ever be treated in one mill, but probably the variation in extraction due to a variation in surface speed of the rollers from 20 to 25 feet per minute or a variation of 20% in the amount of cane treated would be small but still appreciable, provided that the analogy between these experiments and the process of milling is sufficient to allow of this deduction.

This experiment was repeated with bagasse exactly as it was delivered from each one of a train of five mills; the result of the experiment is given below. In this experiment the percentage of fiber in the material under experiment was not determined so that the equivalent tonnage of cane per ton cannot be calculated; however, as the first mill bagasse would contain about 30% of fiber and the fourth and fifth mill material about 45% of fiber the quantities used would correspond to a minimum of about 50,000 lbs. cane per hour to a maximum of about 275,000 lbs. per hour. As before the pressure used was 4740 lbs. per sq. in.

Weight of Bagasse—Lbs.	Percentage of Juice Obtained.				
	Mill I	Mill II	Mill III	Mill IV	Mill V
.441	20.50	21.25	16.00	9.00	8.15
.331	25.00	21.90	18.00	11.33	10.00
.220	27.50	22.50	20.50	12.50	11.50
.110	31.00	26.00	25.60	14.00	14.00

As with the chopped cane decrease in weight of material corresponding with an increase in speed or decrease in tonnage worked gives a regularly increasing amount of juice.

In addition to the bearing, if any, of this experiment on surface speed and tonnage worked in unit time, it may be also correlated with fiber in cane, for with an increase in the fiber in cane the thickness of the layer of bagasse passing between the rollers will also be increased.

Although the results of these experiments point to a benefit to be obtained the use of thin layers of material it is not pretended that they are by any means conclusive, for between the conditions of the experiment and those obtaining in actual practice a wide difference exists.

The volume occupied by bagasse at high pressure. A large number of experiments to determine the relation between the volume occupied by cane fiber under pressure reaching up to 11940 lbs. per sq. in. were made; in all of the experiments made with bagasse it was found that the following relation held for pressures of 500 lbs. per sq. in. and over:

"The volume of cane fiber (or bagasse) varies inversely as the fifth root of the presure" or symbolically $R. P^{.2} = C$ where R is the volume of the residue * and P is the pressure. Since the experiments were performed in cylinders, H may be substituted for R where H is the height of the column of bagasse under pressure; whence $H \ P^{.2} = K$; raising this equation to the fifth power it appears $H^5 \ P = M$ in which form it is most suited for calculation.

It will appear that this relation is of great importance in developing the action of the rollers upon bagasse and accordingly the experiments from which this relation is obtained are described in some detail. In the data presented in the tables below the pressure is given in pounds per sq. in. and is denoted by P; the height of the column of bagasse is given in lineal inches and is denoted by H. In the tables below I give values of $H \ P^{.2}$ and $H^5 \ P$. The first experiments were made in the wheel press with the improvised apparatus mentioned on page 8. These experiments were regarded as of the nature of a preliminary experiment and gave results as follows:

.88 LB. BAGASSE FROM MILL I.

Pressure Lbs. per sq. in.=P.	Height of Column. Ins.=H.	$H \ P^{.2}$	$H^5 \ P$
1025	1.00	4.00	1025
2050	.85	3.92	910
4100	.70	3.70	690
8200	.62	3.75	750

.88 LB. BAGASSE FROM MILL II.

1025	1.29	5.16	3660
2050	1.12	5.15	3620
4100	1.00	5.28	4100
8200	.89	5.40	4580

.88 LB. BAGASSE FROM MILL III.

1025	1.32	5.27	4060
2050	1.12	5.15	3620
4100	1.00	5.28	4100
8200	.85	5.15	3620

With the Olsen machine the following results were obtained:

---

* All these experiments with bagasse were made under such conditions that any juice expressed could freely flow away; the residue consists of fiber and juice; the volume occupied by the juice in the residue is of no account for it simply fills interstitital spaces formed between the particles of fiber.

.441 LB. BAGASSE FROM MILL I.

416	1.39	4.68	2170
1190	1.14	4.71	2330
1780	1.07	4.78	2500
2370	1.01	4.77	2470
2970	.96	4.83	2640
3560	.91	4.67	2220
4160	.88	4.65	2170
4750	.85	4.63	2110

.330 LB. BAGASSE FROM MILL I.

Pressure Lbs. per sq. in.=P.	Height of Column. Ins.=H.	$H P^{.2}$	$H^5 P$
475	1.02	3.49	518
1190	.79	3.25	363
1780	.73	3.26	368
2370	.69	3.26	368
2970	.66	3.26	368
3360	.63	3.23	330
4160	.61	3.23	330
4750	.60	3.26	368

.330 LB. BAGASSE FROM MILL II.

654	.97	3.55	560
1190	.82	3.38	440
1780	.74	3.31	399
2370	.71	3.36	428
2970	.68	3.38	440
3560	.66	3.39	446
4160	.64	3.39	446
4750	.63	3.43	466

.441 LB. BAGASSE FROM MILL III.

654	1.39	5.09	3400
1190	1.16	4.78	2500
1780	1.05	4.70	2300
2370	.99	4.68	2240
2970	.96	4.75	2420
3560	.93	4.77	2470
4160	.91	4.81	2590
4750	.88	4.79	2530

.441 LB. BAGASSE FROM MILL IV.

1190	1.32	5.42	4690
1780	1.22	5.40	4600
2370	1.13	5.35	4390
2970	1.11	5.45	4810
3560	1.05	5.41	4640
4160	1.02	5.40	4600
4750	1.01	5.50	5170

.220 LB. BAGASSE FROM MILL V.

1190	.58	2.39	78.1
1780	.55	2.56	110.0
2370	.53	2.51	99.5
2970	.50	2.47	91.7
3560	.48	2.46	90.4
4160	.47	2.49	96.0
4750	.46	2.45	88.5

On examination of the results tabulated above it will be seen that the expression $H\ P^{.2}$ tends to remain constant and that there is no evidence of a definite increase or decrease in the value with increase of pressure but that the value of $H\ P^{.2}$ oscillates above and below a mean value; the variations from constancy are to be attributed to experimental error. At first sight there appears to be a large variation in the values of $H^5\ P$; the two expressions, being however, different forms of the same law, the variation from constancy is the same in both cases; the measurement of the height of the column of bagasse was attended with considerable difficulty and in one case the error is less apparently owing to the fifth root of the observation entering into the calculation, while in the other case the fifth power is used in obtaining the constant. In these experiments, which were made before the analysis given subsequently had been made, no determination of the fiber in the material under investigation was made. It was apparent on studying these results that in order to apply them to definite calculations, they must be referred to some definite fiber basis, introducing at the same time the size and surface speed of the mill rollers; the method of calculation is given on page 8.

I accordingly made further experiments, employing in these the Riehlé machine and taking quantities of bagasse such that the fiber therein contained represented that contained in 80,000, 100,000, 120,000 lbs. of cane with 12% fiber in a 78″ mill run at 25 ft. per minute. The material in these experiments was obtained by passing cane repeatedly through a hand mill; it was of a texture intermediate between that coming from a second or third mill of a train.

The results of the experiments are given in the tables below; those of the one with .397 lb. bagasse being plotted as a curve in Fig. 9. Examination of these results show that the law already obtained holds equally well up to pressures of 12000 lbs. per sq. in.

As this law, namely that at pressures above 500 lbs. per sq. in. the volume of cane fiber varies inversely as the fifth root of the pressure has been verified in three different machines and with different quantities of material of different origin it will be used

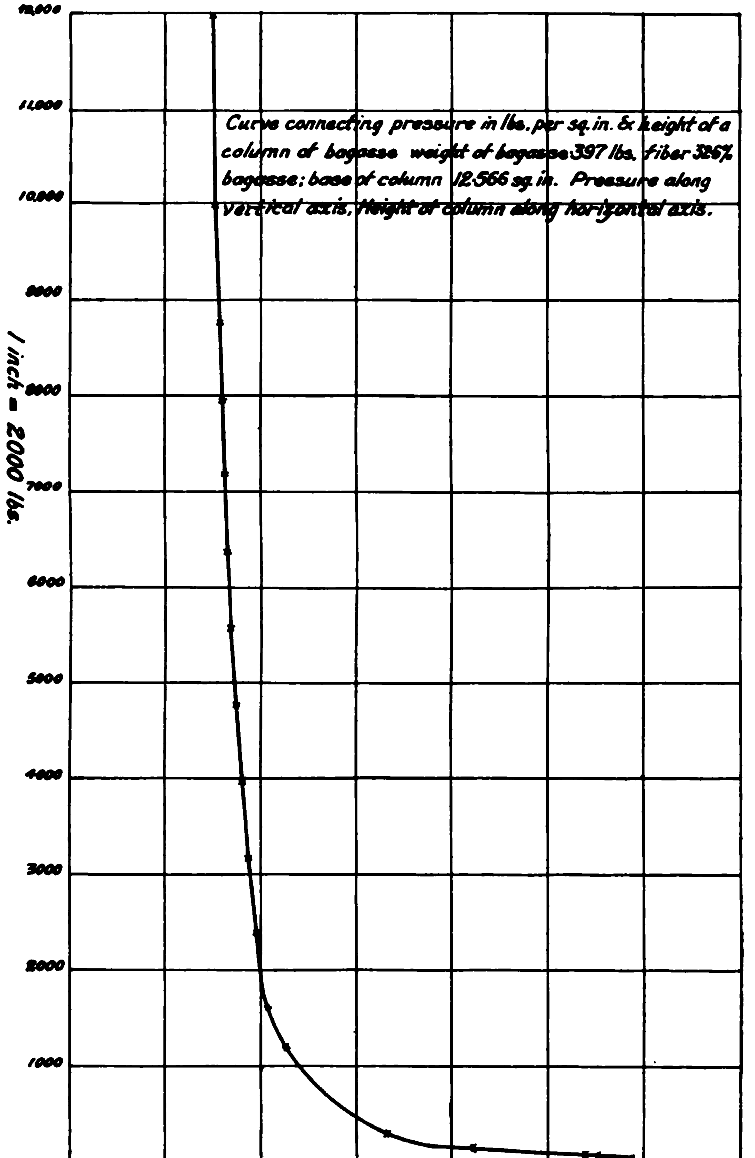
Curve connecting pressure in lbs. per sq. in. & height of a column of bagasse weight of bagasse 397 lbs. fiber 32·6% bagasse; base of column 12·566 sq. in. Pressure along vertical axis, Height of column along horizontal axis.
12,000
11,000
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1 inch = 2000 lbs.
·2
·4
·6
·8
1
1·2
1·4
1" = 1 inch.

FIG. 9

subsequently as a basis for making an analysis of the action of the rollers on crushed cane.

.397 lbs. bagasse corresponding to 120,000 lbs. of 12% fiber cane per hour in 78" mill at a surface speed of 25 ft. per minute.

Pressure Lbs. per sq. in.=P.	Height Inches=H.	$H\ P^{.2}$	$H^5\ P$
31	1.79	3.97	983
83	1.10	2.65	131
162	.845	2.37	73.7
321	.67	2.12	43.0
480	.53	1.85	21.7
640	.52	1.90	24.7
703	.50	1.89	24.2
1193	.465	1.90	24.7
1595	.42	1.84	21.1
2390	.39	1.85	21.7
3187	.37	1.86	22.3
3972	.36	1.82	19.9
4778	.35	1.91	23.2
5574	.34	1.90	24.7
6369	.33	1.91	25.2
7166	.32	1.89	24.2
7980	.315	1.90	24.7
8757	.31	1.91	25.2
10347	.305	1.93	26.5
11940	.30	1.97	29.7

.331 lbs. bagasse corresponding to 100,000 lbs. of 12% fiber cane per hour in 78" mill at a surface speed of 25 ft. per minute.

Pressure Lbs. per sq. in.=P.	Height Inches=H.	$H\ P^{.2}$	$H^5\ P$
42	1.39	2.96	227
83	.935	2.25	58
162	.71	1.97	29.7
321	.575	1.80	18.9
558	.47	1.67	13.0
800	.42	1.63	11.7
1193	.37	1.53	8.4
1595	.34	1.48	7.1
2390	.32	1.53	8.4
3187	.305	1.52	8.1
3972	.29	1.52	8.1
5190	.28	1.51	7.9
6369	.275	1.59	10.2
7980	.26	1.57	9.5
10000	.25	1.57	9.5
11940	.24	1.59	10.2

.264 lbs. bagasse corresponding to 80,000 lbs. of 12% fiber cane per hour in 78" mill at a surface speed of 25 ft. per minute.

Pressure Lbs. per sq. in.=P.	Height Inches=H.	$H\ P^{.2}$	$H^5\ P$
102	.74	1.86	22.3
181	.56	1.59	10.2
340	.44	1.41	5.6
659	.55	1.29	3.6
1000	.30	1.19	2.4
1455	.27	1.15	2.0
2014	.25	1.15	2.0
3206	.24	1.21	2.6
4797	.225	1.22	2.7
6388	.215	1.22	2.7
7980	.210	1.24	2.9
9978	.205	1.30	3.7
11940	.200	1.29	3.6

The Relation Between Pressure and Quantity of Juice Expressed.

As the establishment of a relation connecting these two quantities may be considered of fundamental importance in the design and operation of the mills used for extracting juice from canes some experiments were made to attempt to find some relation or law connecting these two quantities. The experiments were made with the Riehlé machine and were conducted with finely chopped cane. The pressures used reached up to 11940 lbs. per sq. in.; at various intermediate pressures the quantity of juice expressed was measured, simultaneous readings being made of the volume of the residue in the pressure pot. A number of experiments were made, the results of three of which are given in the following tables wherein are tabulated the pressures in lbs. per sq. in., the volume of expressed juice and of residue in c. ins.; the sum of these last two quantities; the weight of juice expressed per cent. on material used; the fifth root of the pressure and the product of the volume of the residue and the fifth root of the pressure. In Fig. 10 is given the curve connecting the weight of juice expressed, the pressures being plotted along the horizontal and weights of juice per cent. on material employed along the vertical axis; the data used in following this curve are those tabulated in the first table following. It will be observed that with the high pressures that the sum of the volumes of juice expressed and of residue remain constant; that is to say, every decrease in volume of the material contained in the pressure pot is accompanied by an outflow of juice of exactly the same volume. That is to say, the material contained in the pot may be regarded as made of solid (fiber) immersed in a liquid (juice) the inter-

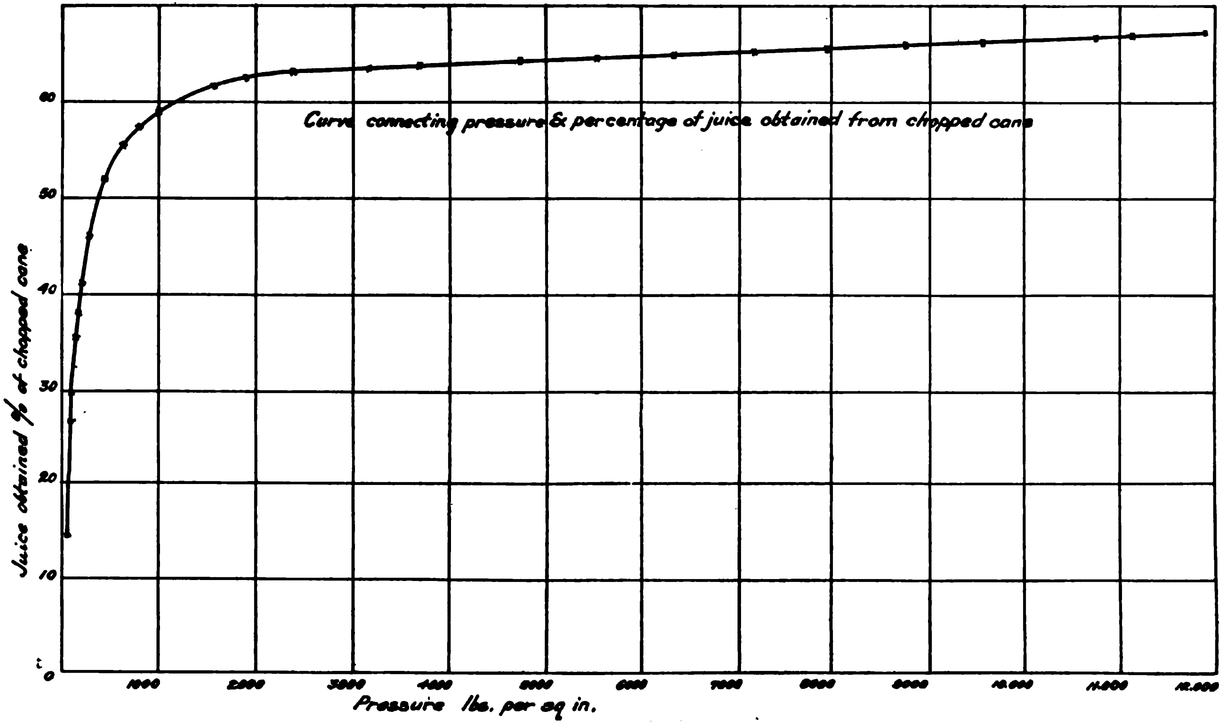
Curve connecting pressure & percentage of juice obtained from chopped cane
Juice obtained % of chopped cane
60
50
40
30
20
10
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
11,000
12,000
Pressure lbs. per sq in.

FIG. 10

stitial spaces between the particles of fiber being completely filled with liquid and hence the expression of juice is due entirely to the closer packing of the solid particles under the increase in pressure, that is to say, to a decrease in the apparent volume of the solid particles.

In the previous section it was shown that the relation $R.\ P^{.2} =$ constant where R is the volume of cane fiber and P the pressure under which the cane fiber occupies the volume R held. On inspection of the results obtained with chopped cane given in the tables on page 25 it will be seen that it is only with the very highest pressures that the relation tends to become constant and that there is a general increase in the product $R\ P^{.2}$ as the pressure increases; this would imply that at lower pressures when dealing with chopped cane the exponent in the equation $R\ P^{x} =$ constant is not actually a constant but increases slowly as the pressure increases; to determine in what manner the exponent varied with the pressure I took the last values obtained in the table on page 25, namely $P = 11940$, $R = 23.5$; at this point $R\ P^{.2} = 154$; taking this value as the constant I then calculated the value of x in the equation $R\ P^{x} = 154$ for values of R and P for $R = 30.8$ and $P = 1000$. As a result of the calculation x is found to be .233 when $R = 30.8$ and $P = 1000$; as the pressure increases there is a gradual decrease in the valve of x until the region of pressure of the order 8000 lbs. per sq. in. or over is reached when x is found to be very close to .2; as an approximation this relation results:

$$R\ P^{.2 + [3 \text{ x } 10^{-6} (12000 - P]} = \text{constant}$$

and this holds for values of P lying between 1000 and 12000. It has however, been already shown that when dealing with bagasse the simple relation $V\ P^{.2} =$ constant holds and with small error this relation holds with crushed cane when $P = 6000$ or over; and in no case does the value of the exponent vary much from .2; it would then be sufficient to take the volume of fiber as inversely proportional to the fifth root of the pressure. When dealing with chopped cane it was found that the sum of the volume of the residue and expressed juice was a constant or symbolically $J + R = C$ whence $R = C - J$. The following equation connecting the juice expressed with pressure then results:

$$(C - J)\ P^{.2} = \text{constant}$$

The relation between quantity of juice expressed and pressure can, however, be approximately expressed with the use of only one constant; the juice expressed increases directly with some function of the pressure; if this function be some root then since the increase in the volume of the juice is the same as the decrease in the volume of the residue and since at high pressure as the volume of the juice is greater than the volume of the residue this root must be smaller than the fifth which was found to hold in the expression $H P^{.2}$ = constant. By trial and error it was found that for pressures above 1000 lbs. per sq. in. the expression $\frac{J}{P^{.083}}$ increased very slowly, that is to say the volume of the juice expressed at high pressures is approximately proportionate to the twelfth root of the pressure; values of $\frac{J}{P^{.083}}$ and given in the last column in the table on page 25.

An exponent varying with P can be introduced as was done when expressing the relation between R and P when it will be found for pressures over 1000 lbs. per sq. in. the following relation holds:

$$J P^{-.083} - [.9 \times 10^{-6} (12000 - P)] = C$$

Volume and Weight of Juice and Volume of Residue Obtained on Pressing 3.410 lbs. Chopped Cane up to 11940 lbs. per sq. in.

Pressure Lbs. per sq. in.=P.	Volume of Juice C. in.=J.	Weight of Juice % on Cane.	Volume of Residue C. in.=R.	J + R	$R P^{.2}$	$J P^{-.083}$
68	13.2	14.8	75.5	88.7	176	...
83	13.1	20.3	70.0	88.1	169	...
104	23.7	26.5	63.4	87.1	160	...
123	26.6	29.8	60.2	86.8	158	...
162	31.5	35.2	54.1	85.6	150	...
203	34.1	38.1	50.9	85.0	147	...
242	36.6	41.0	47.6	84.2	143	...
321	41.0	45.9	42.6	83.7	135	...
406	43.7	50.9	40.1	83.8	133	...
480	46.0	51.5	37.1	83.0	130	...
640	49.6	55.9	33.5	83.2	122	...
800	51.3	57.4	32.1	83.3	122	...
1000	53.3	58.6	30.8	84.1	122	32.9
1193	53.7	60.1	29.8	83.4	122	33.4
1595	54.9	61.4	28.6	83.5	125	33.2
1993	55.5	62.1	28.2	83.7	129	33.0
2390	56.2	62.9	27.6	83.8	131	32.9
3187	56.5	63.3	27.1	83.6	136	32.3
3972	57,2	64.0	26.6	83.8	140	32.1
4778	57.6	64.5	26.2	83.9	142	31.8
5574	57.8	64.7	26.0	83.7	146	31.5
6369	58.0	64.9	25.7	83.7	148	31.4
7166	58.3	65.3	25.5	83.8	150	31.2
7959	58.4	65.4	25.2	83.7	151	31.0
8757	58.9	65.9	24.9	83.7	153	35.9
9555	59.0	66.1	24.5	83.5	153	30.8
10747	59.6	66.7	24.0	83.5	154	30.5
11145	60.0	67.1	23.7	83.7	153	30.9
11940	60.2	67.3	23.5	83.7	152	30.8

Volume and Weight of Juice and Volume of Residue Obtained on Pressing 2.645 lbs. Chopped Cane up to 11940 lbs. per sq. in.

Pressure Lbs. per sq. in.=P.	Volume of Juice C. in.=J.	Weight of Juice % on Cane.	Volume of Residue C. in.=R.	$J + R$	$R\,P^{.2}$	$J\,P^{-.083}$
1595	42.4	62.9	20.5	62.9	89	34.0
2390	44.2	65.6	18.6	62.8	88	34.3
3187	45.1	67.0	17.9	63.0	90	34.2
3972	....	...	17.5	...	90	...
4778	....	...	17.0	...	93	...
5574	47.3	70.1	16.7	64.0	94	34.2
6369	....	...	16.5	...	95	...
7166	47.7	70.7	16.2	63.9	96	33.8
7601	....	...	16.0	...	96	...
8757	....	...	15.8	...	97	...
9555	48.2	71.6	15.7	64.0	98	33.6
10747	....	...	15.5	...	99	...
11145	....	...	15.3	...	99	...
11940	48.7	72.4	15.2	63.9	99	33.1

Volume and Weight of Juice and Volume of Residue Obtained on Pressing 3.30 lbs. Chopped Cane up to 11940 lbs. per sq. in.

Pressure Lbs. per sq. in.=P.	Volume of Juice C. in.=J.	Weight of Juice % on Cane.	Volume of Residue C. in.=R.	$J + R$	$R\,P^{.2}$	$J\,P^{-.083}$
1595	50.6	60.3	28.0	78.6	122	32.6
2390	...	...	26.0	...	123	...
3187	55.4	66.0	25.5	80.9	128	35.4
3972	...	...	25.3	...	133	...
4778	56.1	66.8	25.0	81.8	136	32.9
5574	...	...	24.6	...	138	...
6369	...	...	24.1	...	139	...
7166	57.0	67.9	23.6	80.6	139	32.5
7601	...	...	23.4	...	140	...
8757	57.7	68.7	23.2	80.9	143	32.2
9555	...	...	23.0	...	144	...
10747	58.0	69.0	22.9	80.9	147	31.8
11145	...	...	22.7	...	149	...
11949	58.2	69.3	22.6	80.8	148	31.7

The Volume Occupied by Bagasse at Lower Pressures. The experiments, an account of which has been given in the preceding pages, dealt with higher pressures. The apparatus employed there was not suited for the accurate determination of lower pressures; I accordingly made use of a different scheme for obtaining the relation between volume and pressure at lower pressures. The apparatus consisted of a pressure pot similar to the one already described (page 6); pressure was applied by placing on the top of the plunger cylindrical lead weights; the arrangement of the apparatus is shown in Fig. 11; the weights used weighed 200 lbs., 100 lbs., 50 lbs.; they were raised by a block and tackle and lowered very gently on to the plunger so as to avoid as much as possible any shock; the weights were cylindrical and could thus be placed exactly on top of each other; after the plunger had sunk into the cylinder and come to rest a measurement of the height projecting over the top of the pot was made whence could be obtained the volume occupied by the bagasse under the existing pressure.

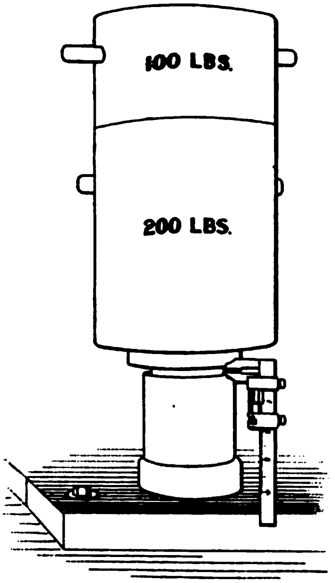

Fig. 11

In these experiments the material employed was obtained by passing cane repeatedly through a hand mill; it was substantially of the same texture and state of division as a typical third mill bagasse. The results of experiments are given in the tables on pages 28 to 30, and the results of one are plotted as a curve in Fig. 12.

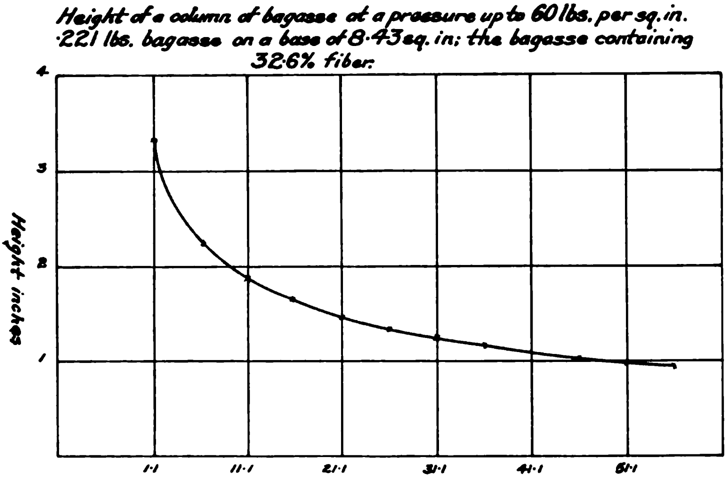

Fig. 12

On inspection of the curve it was suspected that some relation as H P^x = constant would hold where H is the height of the column of bagasse under a pressure P and that probably x would be close to .5; on working out values of H $P^{.5}$ it was found that these gradually increased indicating an exponent smaller than .5; by trial and error it was found that the relation H $P^{.4}$ = constant held with satisfactory accuracy; the values of H $P^{.4}$ are given in the tables on pages 28 to 30 together with the data of the experiments; the deviation of $P^{.4}$ from constancy are largely due to shock unavoidable in removing and placing on the heavy weights. This experiment establishes for one particular sample of bagasse the relation H $P^{.4}$ constant; while it would be possible that for all samples of bagasse a relation of the form P^n = constant would hold the value of the exponent might vary with the mechanical condition of the sample; accordingly three samples of bagasse were prepared coarse, medium or fine; the first would represent substantially the material coming from a second mill and the last would represent a material coming from a fourth mill; these samples were subjected to pressure as already described; the results of the experiment are given in the tables on pages 28-30; inspection of these results there tabulated shows that the relation H $P^{.4}$ = constant holds equally well for the three samples and as already found when pressing chopped cane (page 13) the finest material is pressed to the smallest volume.

These results then may be formulated in the statement that at low pressures the volume of bagasse varies inversely as the 2.5th root of the pressure or symbolically H $P^{.4}$ = constant when H is a measure of the volume and P the pressure.

Height of .221 lb. bagasse containing 32.6% fiber on a surface of 8.43 sq. in. corresponding to 100,000 lbs. cane containing 12% fiber per hour at a surface speed in rollers of 25 ft. per minute in a 78" mill under pressures up to 60 lbs. per sq. in.

Pressure Lbs. per sq. in.=P	Height Inches=H	H $P^{.4}$
1.1	3.358	4.90
6.1	2.238	4.51
11.1	1.889	4.96
16.1	1.658	5.01
21.1	1.467	4.99
26.1	1.333	4.92
31.1	1.283	5.09
36.1	1.183	4.96
41.1	1.100	4.85
46.1	1.039	4.80
51.1	.989	4.77
56.1	.944	4.74

Height of .177 lb. bagasse containing 32.6% fiber on a surface of 8.43 sq. in corresponding to 80,000 lbs. cane containing 12% fiber per hour at a surface speed in rollers of 25 ft. per minute in a 78" mill under pressures up to 60 lbs. per sq. in.

Pressure Lbs. per sq. in.=P	Height Inches=H	H $P^{.4}$
1.1	2.615	3.83
6.1	1.715	3.45
11.1	1.396	3.68
16.1	1.224	3.70
21.1	1.065	3.62
26.1	.943	3.50
31.1	.890	3.51
36.1	.844	3.53
41.1	.812	3.60
46.1	.787	3.67
51.1	.764	3.09
56.1	.742	3.09

Height of .132 lb. bagasse containing 34.0% fiber on a surface of 8.43 sq. in. corresponding to 62,600 lbs. of cane containing 12% fiber on a surface speed of 25 feet per minute in a 78" mill at pressures up to 60 lbs. per sq. in.

Pressure Lbs. per sq. in.=P	Height Inches=H	H $P^{.4}$
11.1	1.118	2.93
31.1	.745	2.94
51.1	.601	2.91
56.1	.571	2.86

Height of .177 lb. bagasse, containing 34.0% fiber on a surface of 8.43 sq. in. corresponding to 83,500 lbs. of cane containing 12% fiber and a surface speed of 25 feet per minute in a 78" mill at pressures up to 60 lbs. per sq. in.

Pressure Lbs. per sq. in.=P	Height Inches=H	H $P^{.4}$
11.1	1.647	4.32
31.1	1.035	4.10
51.1	.891	4.30
56.1	.881	4.42

Height of .221 bagasse containing 34.0% fiber on a surface of 8.43 sq. in. corresponding to 104,000 lbs. of cane containing 12% fiber and a surface speed of 25 feet per minute in a 78" mill at pressures up to 60 lbs. per sq. in.

Pressure Lbs. per sq. in.=P	Height Inches=H.	$H P^{.4}$
11.1	2.026	5.33
31.1	1.296	5.19
51.1	1.128	5.44
56.1	1.080	5.43

Height of .265 bagasse containing 34.0% fiber on a surface of 8.43 sq. in. corresponding to 125,000 lbs. cane containing 12% fiber and a surface speed of 25 feet per minute in a 76" mill at pressures up to 60 lbs. per sq. in.

Pressure Lbs. per sq. in.=P	Height Inches=H.	$H P^{.4}$
11.1	2.440	6.41
31.1	1.586	6.35
51.1	1.337	6.46
56.1	1.284	6.46

Height of .221 lb. bagasse, the bagasse containing 38.0% fiber on a surface of 8.43 sq. in. corresponding to 116,000 lbs. of cane containing 12% fiber and a surface speed of 25 feet per minute in a 78" mill, at pressures up to 60 lbs. per sq. in.

Pressure Lbs. per sq. in.=P	Height Inches=H.	$H P^{.4}$
	FINE.	
11.1	2.051	5.08
31.1	1.341	5.33
51.1	1.018	5.30
56.1	1.066	5.36
	MEDIUM.	
11.1	2.000	5.24
31.1	1.384	5.46
51.1	1.108	5.34
56.1	1.083	5.42
	COARSE.	
11.1	2.152	5.59
31.1	1.412	5.59
51.1	1.181	5.70
56.1	1.133	5.69

The Volume Occupied by Finely Divided Cane Fiber Under Pressure Up to 4000 lbs. per sq. in. The experiments already described have dealt with bagasse and choped cane; it was thought that the same law converting volume and pressure would apply to such a material as finely divided cane fiber and an apparatus was devised for use with finely divided cane fiber such that a large range of pressing could be employed and the volume measured with great accuracy.

This apparatus was used with the intention of obtaining a more accurate representation of the results already obtained and described; the apparatus employed was that described on p .. and shown in Fig. 6. The details of an experiment are as follows: A quantity of dry and finely divided cane fiber corresponding to a certain tonnage of cane as calculated by the method given on page 8 was weighed out, and introduced into the hollow brass cylinder *aa*, Fig. 6; the weight of the plunger *dd* and the plate *ee* being 2.8 lbs.; the introduction of this part of the apparatus into the cylinder *aa* gave a pressure of 57 lbs. per sq. in. on the surface of the fiber therein contained; the higher pressures were obtained by placing the lead weights (see page 27) on the plate *ee*; the maximum load placed thereon was 200 lbs., corresponding to a pressure of over 4000 lbs. per sq. in.

The pressures lower than 60 lbs. per sq. in. were obtained by substituting for the steel plunger and plate a much lighter plunger made out of a glass rod on one end of which was fixed a flat support for carrying weights up to three pounds.

A number of experiments were made with this apparatus of which the complete data are given in the tables on pp. .. and .. whence it appears that with finely divided cane fiber a quite different law obtains from that found to hold with bagasse and chopped cane. Inspection of the results on pp. 32-33 shows that for pressures reaching up to 4000 lbs. per sq. in. the volume of finely divided cane varies inversely as the square root of the pressure or symbolically $R\ P^{.5} =$ constant.

When this experiment was devised it was anticipated that the exponent in the equation $R\ P^{n} =$ constant would gradually increase; evidently the behavior of finely divided cane fiber under pressure is different from that of bagasse or chopped cane; and it is not suggested that these experiments with finely divided cane fiber have any bearing on the problems associated with milling; with one isolated phase of cane sugar technology, namely the baling of commercially dried cane for export they have a very direct connection.

Height of .0003178 lb. finely divided fiber on a surface of .04909 sq. in. corresponding to 60,000 lbs. cane containing 12% fiber in a 78" mill run at 25 ft. per minute:

Pressure Lbs. per sq. in.=P	Height Inches=H	$H\ P^{.5}$	Pressure Lbs. per sq. in.=P	Height Inches=H	$H\ P^{.5}$
10	1.650	5.214	500	.336	7.516
20	1.383	6.477	600	.312	7.598
30	1.216	6.660	700	.285	7.272
40	1.088	6.885	800	.265	7.496
50	1.008	7.129	900	.255	7.638
60	.890	6.783	1000	.240	7.638
80	.839	7.496	1200	.230	7.985
100	.790	7.903	1400	.210	7.842
120	.739	8.107	1600	.193	7.740
140	.672	7.964	1800	.183	7.760
160	.640	8.107	2000	.173	7.720
180	.583	7.821	2200	.165	7.720
200	.534	7.557	2400	.157	7.700
260	.468	7.557	2600	.149	7.455
300	.432	7.496	2800	.145	7.638
400	.377	7.536	3000	.141	7.699
460	.348	7.475	3200	.138	7.842

Height of .00004226 lb. finely divided cane fiber on a surface of .04909 sq. in. corresponding to 80,000 lbs. cane containing 12% fiber in a 78" mill run at 25 ft. per minute:

Pressure Lbs. per sq. in.=P	Height Inches=H	$H\ P^{.5}$	Pressure Lbs. per sq. in.=P	Height Inches=H	$H\ P^{.5}$
10	2.896	9.166	500	.371	9.089
20	2.151	10.022	700	.344	9.146
30	1.748	9.554	800	.324	9.166
40	1.548	9.777	900	.301	9.065
50	1.391	9.838	1000	.287	9.085
60	1.057	9.085	1200	.265	9.166
80	1.041	9.288	1400	.248	9.288
100	.974	9.737	1600	.234	9.369
120	.898	9.869	1800	.226	9.594
140	.825	9.777	2000	.216	9.655
160	.766	9.696	2200	.210	9.838
180	.717	9.635	2400	.202	9.879
200	.684	9.676	2600	.198	9.919
260	.599	9.676	2800	.187	9.919
300	.542	9.594	3000	.179	9.777
360	.481	9.125	3200	.171	9.716
400	.462	9.247	3400	.167	9.716
460	.440	9.451	3600	.161	9.655
500	.418	9.329	3800	.159	9.777

Height of .0005274 lb, finely divided cane fiber on a surface of .04909 sq. in. corresponding to 100,000 lbs. cane containing 12% fiber in a 78" mill run at 25 ft. per minute:

Pressure Lbs. per sq. in.=P	Height Inches=H	$H P^{.5}$	Pressure Lbs. per sq. in.=P	Height Inches=H	$H P^{.5}$
10	3.465	10.816	600	.503	12.322
20	2.530	11.346	700	.464	12.322
30	2.129	11.752	800	.434	12.301
40	1.829	11.569	900	.411	12.343
50	1.644	11.630	1000	.389	12.301
60	1.519	11.325	1200	.361	12.465
80	1.344	12.018	1400	.340	12.730
100	1.218	12.180	1600	.316	12.628
120	1.151	12.506	1800	.293	12.424
140	1.012	11.996	2000	.279	12.465
160	.961	12.160	2400	.257	12.587
180	.912	12.261	2600	.242	12.363
200	.876	12.403	2800	.234	12.404
260	.774	12.506	3000	.226	12.383
300	.709	12.281	3200	.220	12.444
360	.650	12.363	3400	.212	12.363
400	.627	12.547	3600	.206	12.432
460	.576	12.342	3800	.200	12.322
500	.540	12.017	4000	.194	12.241

PART II.

APPLICATION OF THE EXPERIMENTS DESCRIBED IN PART *I* TO THE PROCESS OF MILLING.

The experiments described on pages 26-30 were made with the object of determining the effect of different settings of the trash turner, the pressure thereon, the loss of power therein and the relation between fiber in cane or tonnage milled hourly and the setting. As a preliminary I obtained a full scale drawing of a 34"x78" mill with the trash turner drawn in to different settings, this drawing is shown to a scale of ¼ in Fig. 13. As a basis a feed opening of ⅜" and a discharge of zero was adopted with the mill at rest; under working conditions it was accepted that the discharge opening becomes .25 inch obtained by a vertical lift of the top roller through the same distance. The settings adopted for the trash turner started with one of 1 inch below the lowest point of the top roller with the mill at rest; this dimension will be referred to below as the *'drop'*; with a drop of 1 inch at rest the drop under working conditions will become 1.25 inches. The clearance between the trash turner and back roll is taken uniformly at .625 inch. In Fig. 13 is given the

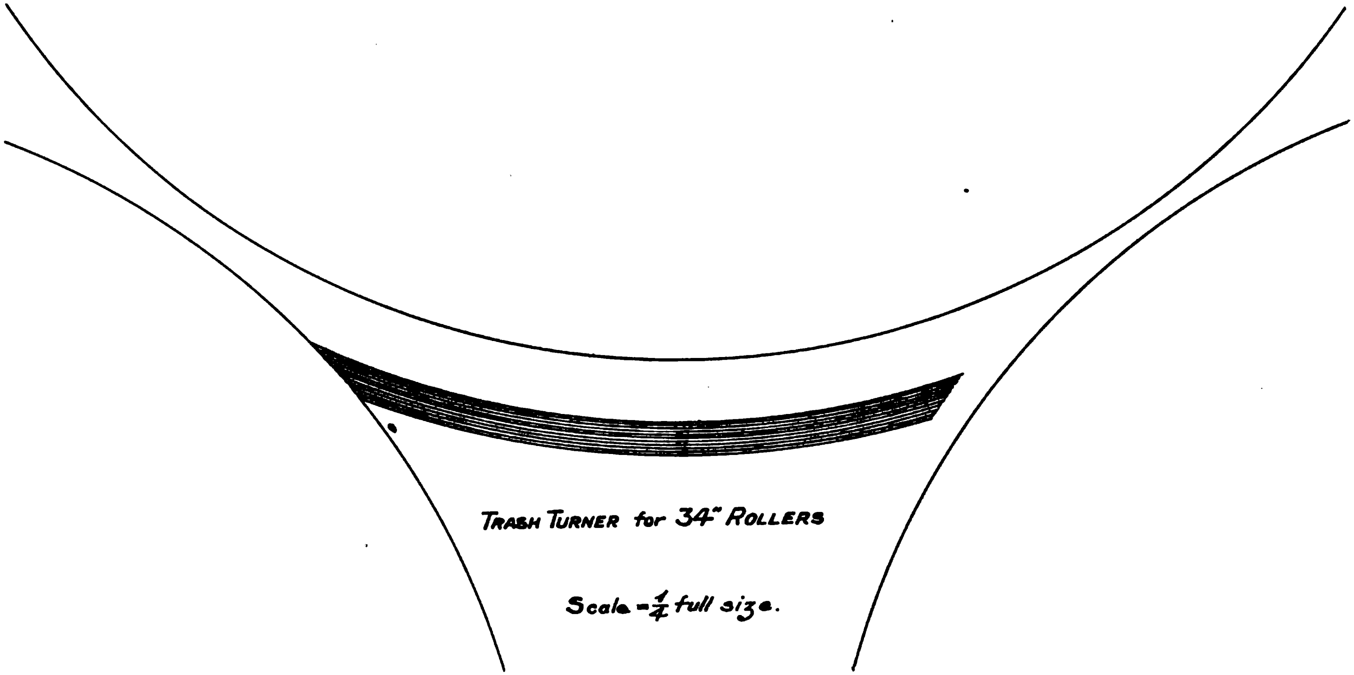
Trash Turner for 34" Rollers
Scale – $\frac{1}{4}$ full size.

Fig. 13

position of the trash turner for drops of from 1 inch (at rest) to 1.625 inches, increasing by sixteenths of an inch (.0625 inch); all the trash turner curves are drawn from one center; the horizontal distance between the bottom rollers was taken as six inches corresponding to an apical angle of 72°.

Average pressure on trash turner. It has been shown by the experiments described on page 26 that at low pressures the volume of bagasse varies as the .4th power of the pressure. Hence if the drop of the trash turner at the inlet be 1 inch and at outlet be 1.5 inches the average pressure on the trash turner is not that due to a column of bagasse 1.25 inches high; accordingly to the law experimentally determined the average pressure can be determined thus:

The general equations of $H\ P^{.4} = \text{constant}$ can be written $H^{2.5}\ P = \text{constant}$. In Fig. 14 is given the curve $H^{2.5}\ P = \text{constant}$ for values of H from 1 inch to 2 inches and for a constant of value 50. The value of the constant was taken as 50 on the following argument: When pressing bagasse of medium texture it was found (see p. 3) that with bagasse corresponding to 116,000 lbs. cane containing 12% fiber and a surface speed of 25 feet per minute $H\ P^{.4}$ equalled on an average 5.36 corresponding to a value of 4.62 for 100,000 lbs. cane per hour; in the series on page 30 the corresponding value of $H\ P^{.4}$ was 4.75; the average of these values is 4.68; taking this value as the constant the value of $H^{2.5}\ P$ is 49.14 and taking into account the difficulties of the experiment the variation which may be expected from sample to sample this number may be rounded off as 50. Now referring to the curve in Fig. 14 evidently the area under the curve bounded by any two ordinates represents the total pressure and this total pressure divided by the horizontal distance between the ordinates gives the mean ordinate or the mean presure.

Writing x for H and y for P the equation to the curve Is $x^{2.5}y = 50$ or $y = 50\ x^{-2.5}$ or generally $y = M\ x^{-n}$. Then integrating between the limits $n = a$, $n = b$ the area under the curve and between the ordinates a and b is:

$$\int_a^b m\ x^{-n}\ d\ x = \frac{m}{1-n}\left\{ b^{1-n} - a^{1-n} \right\}$$

Substituting actual values let it be required to find the mean value of y between the points $x = 1.09$ and $x = 1.50$. The area of the curve is:

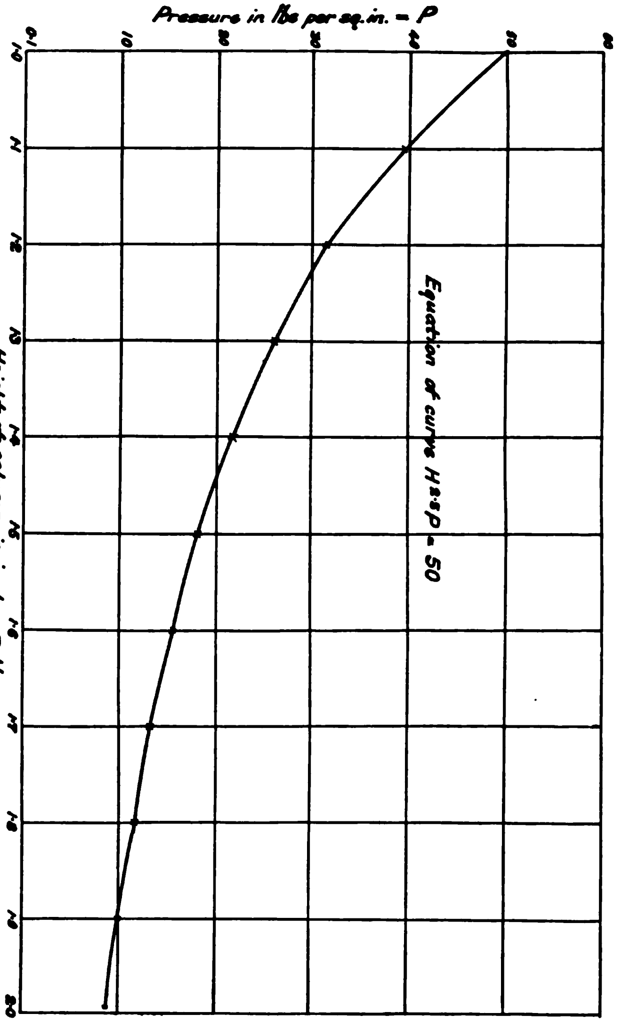

FIG. 14

$$\int_{1.09}^{1.50} 50\,x^{-2.5}\,dx = \frac{50}{1-2.5}\left\{1.50^{1-2.5} - 1.09^{1-2.5}\right\}$$

This number divided by the base = .4 gives *27.2* as the mean ordinate, that is to say the average pressure due to a layer of bagasse in which the height increases lineally from 1.09 to 1.50 inches is 27.2 lbs. per sq. in., the quantity of bagasse being that corresponding to that contained in 100,000 lbs. of cane containing 12% of fiber.

Substituting 27.2 for P in the equation

$$H^{2.5}P.=50$$

and solving for H, H is found to be 1.29, that is to say the pressure due to a layer of bagasse increasing in height from 1.09 to 1.50 inches and when the pressure varies inversely as the 2.5th power of the height is the same as that of a layer of a uniform height of 1.29 inches; this expression I call the *mean drop* and in the penultimate column of the table on page 37 I have tabulated the mean drop for each different setting and in the last column I have tabulated the mean *pressure* in lbs. per sq. in. as calculated from the equation $H^{2.5}$ $P = 50$ for H in inches and P in lbs. per sq. in.

Dimensions, etc., of trash for 34"x78" mill with apical angle of 72° for drops at rest of 1 inch to 1.625 inch and clearance from back roller of 6.25 inch:

Drop at rest—Inches.	Drop working—Inches.	Drop at feed—Inches.	Drop at discharge—Inches.	Length—Inches.	Area—Square inches.	Projection on horizontal plane—Inches.	Mean drop—Inches.	Mean pressure—Lbs. per sq. in.
1	1.25	1.09	1.50	14.5	1131	1092	1.29	27.2
1.06	1.31	1.15	1.57	14.3	1115	1071	1.34	24.0
1.125	1.375	1.22	1.15	14.1	1100	1061	1.41	24.1
1.19	1.44	1.28	1.80	13.9	1084	1045	1.48	18.7
1.25	1.50	1.35	1.72	13.7	1089	1030	1.56	16.5
1.31	1.56	1.42	1.88	13.5	1053	1014	1.63	14.7
1.375	1.625	1.48	1.95	13.3	1037	998	1.70	13.2
1.447	1.69	1.55	2.02	13.1	1022	990	1.77	12.0
1.500	1.75	1.61	2.09	12.9	1006	975	1.83	11.0
1.506	1.81	1.64	2.17	12.7	991	960	1.90	10.0
1.675	1.775	1.75	2.25	12.5	975	952	1.98	9.1

Variation in Pressure on Trash Turner with Variation in Drop. The total pressure on the trash turner will be the product of the pressure due to the mean drop into the projected area of the trash turner on a horizontal plane; this quantity will also be the pressure acting vertically upwards on the top roller the effect of which will be to diminish the pressure due to the hydraulic load. In the following table is given the pressure on the trash turner for the settings tabulated in the table on page 37; these pressures of course refer to the exact conditions for which the latter was calculated, i. e., for 100,000 lbs. of cane containing 12% fiber, per hour, in a 34″x78″ mill worked at a speed of 25 feet per minute. It will be seen that with the trash turner settings adopted an increase in the drop not only decreases the pressure due to the fall in the mean pressure but also to the diminished area of the trash turner.

Drop at Rest—Inches.	Total Pressure—Lbs per sq. in.	Drop at Rest—Inches.	Total Pressure—Lbs per sq. in.
1	29,700	1.575	13,200
1.06	25,800	1.44	11,900
1.625	22,400	1.50	10,700
1.19	19,600	1.56	9,600
1.25	17,000	1.625	8,600
1.31	14,900	....	.....

Variation in Pressure on Trash Turner Due to Variation in Fiber in Cane. If the fiber in cane increases above the adopted standard of 12% then, other conditions remaining the same, to obtain the same pressure on the trash turner the drop must evidently be increased in direct proportion to the increase in the fiber content; if, however, there is a variation in the fiber content and the setting remains unaltered the pressure on the trash turner will increase in proportion to the 2.5th power of the increase in the fiber content. Adopting as a basis of comparison a drop at rest of 1.31 inches for the standard conditions the following table gives the mean pressure in lbs. per sq. in. on the trash turner for different fiber contents with the same setting; the calculation is made as follows: if with 12% fiber a certain setting gives a pressure of 14.7 lbs. per sq. in. with 13% fiber the same setting will give a pressure of

$$\left(\frac{13}{12}\right)^{2.5} \times 14.7 = 17.9$$

Comparative pressures on trash under turner due to variation in fiber:

Fibre in Canes.	Pressure compared with that due to a cane containing 12% of fiber.	Pressure—Lbs. per sq. in.
10	.63	9.3
10.5	.71	10.5
11	.80	11.5
11.5	.90	13.2
12	1.00	14.7
12.5	1.11	16.3
13	1.22	17.9
13.5	1.34	19.7
14	1.47	21.6
14.5	1.61	23.7
15	1.75	25.7

Variation in Pressure on Trash Turner Due to Variation in Quantity Milled. Evidently the effect will be precisely the same as that due to variation in the fiber, that is to say the same pressure will be obtained on the trash turner with increasing quantity of cane when the drop is increased in the same proportion. If the setting remains the same the pressure will vary as the 2.5th power of the tonnage milled.

Variation in Pressure on Trash Turner Due to Variation in Surface Speed of Roller. With an increase in surface speed the height of the layer of bagasse decreases lineally with the speed; the pressure on the trash turner will therefore decrease with the 2.5th power of the surface speed. It hence follows that so far as regards the pressure of the trash turner that an increase in fiber content of the cane milled can be neutralized by an increase in the surface speed of the rollers; that is to say the same setting may be maintained independent of the fiber in the cane by varying the speed so as to have a constant quantity of fiber on the trash turner.

Power Absorbed by Passage of Bagasse Over the Turner. The data already obtained are sufficient to allow of an estimate of the power absorbed in friction in the trash turner. As an example the standard conditions forming the basis of the previous calculations may be used, namely 100,000 lbs. of cane containing 12% fiber in a 34″x78″ mill worked at a surface speed of 25 feet per minute, and a drop at rest in the trash turner of 1.31 inches. Under these conditions the area of the trash turner is 1053 sq. in. and the pressure of the bagasse is 14.7 lbs. per sq. in. so that the total pressure exacted by the bagasse is 15,479 lbs. The angle of friction of bagasse on iron is 22° which corresponds to a coefficient of friction of 0.4.

The speed of the layer of bagasse being 25 feet per minute the foot pounds per minute necessary to draw the bagasse over the trash turner are

$$15479 \times .4 \times 25 = 154790$$

and the horse power required is

$$\frac{154790}{33000} = 4.68 \text{ H. P.}$$

Pressure of Bagasse at Any Point. By means of the experiments described in the preceding pages it is possible to make some analysis of the actual state of affairs in the process of crushing. To begin with it may be advisable to recall some geometrical properties of circles. In Fig. 15 let a c e be a circle to which a tangent is drawn at the point c; from a let a perpendicular a b be drawn to the tangent; then denoting b c by 1, a b by d and o a by r

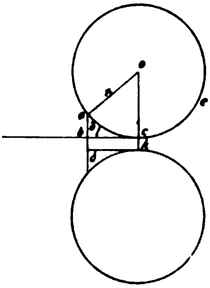

FIG. 15

$$d = r - \sqrt{r^2 - l^2}$$

Now let there be two similar circles (Fig. 15) separated by a distance k; then for any distance 1 measured along a tangent at the nearest point of approach of the circles

$$H = k + 2\left(r - \sqrt{r^2 - l^2}\right)$$

where H is the distance between the rollers at any point 1, and k is the distance at the point of nearest approach.

Now let the two circles in Fig. 15 represent two rollers; then when the diameter of the rollers (2r) and the distance at the point of nearest approach (k) are known, the distance apart (H) at any point can be expressed in terms of 1 where 1 is the distance from the point of nearest approach measured along the tangent at the point of nearest approach. Further it has been already shown that the relation $R P^{.2}$ = constant holds where R is the volume of bagasse under pressure P; when the base of this column of bagasse under pressure is constant for R we can put H where H is the height of the column and raising the expression to the fifth power we can write.

$$H^5 P = \text{constant}$$

I then proceeded to the calculations described below. Referring to the tabulated results on pp. 32 and 33 it will be seen that to average value of H^5 P for quantities of material corresponding to 120,000, 100,000, 80,000 lbs. of cane per ton in a 78″ mill will run at 25 ft. per minute and calculated for pressures of 500 lbs. per sq. in. in and over is 1.89, 1.55, 1.26; referring all these experiments to a basis of 100,000 lbs. per hour an average value is obtained for $H\ P^{.2}$ of 1.57 so that $H^5\ P = 9.5$; this value will be accepted in the calculations which follow.

Before any estimate could be made of the pressure on the layer bagasse in its passage between the rollers it was necessary to know the distance at the line of nearest approach, i. e., k in the equation above, when a certain definite quantity of material was being milled; as far as the writer is aware there are very few observations of the measurement on record. The most detailed account to which I have access is a manuscript translation from the Dutch and refers to rigid mills. In a *rigid* mill the setting at rest is the same as that when working except for deformity produced by the pressure; in a mill worked under hydraulic pressure the position of the rollers under working conditions is a function of the pressure, of the quantity of the material milled and of the surface speed of the rollers. The mills considered in this publication were nearly all 30″x60″; the average surface speed was 16.0 feet per minute; the average feed opening was .520 inch and the average delivery opening was .222 inch, the average quantity of cane crushed was 51,000 lbs. per hour; referred to a basis of a 78″ mill worked at 25 feet per minute this corresponds very closely with 100,000 lbs. cane per hour; from the few observations I have been able to collect of mills worked under hydraulic pressure a similar opening exists between the back and top roller; accordingly as a basis of calculation I have taken k in the equation above as .25 inch, that is to say, it is assumed as a basis of calculation under average working conditions at the final squeeze the rollers approach to .25 inch and this is the minimum height of the column of bagasse at the point of greatest pressure.

In the table on page 42 is given the pressure exerted on the layer of bagasse in its passage between the rollers for distances up to three inches from the line of nearest approach; this calculation refers to 100,000 lbs. of cane containing 12% fiber milled at a surface speed in the rollers of 25 ft. per minute. In the left hand column are entered up the distances from the line of nearest approach, i. e., l in the equation on p. 40. The captions in the top horizontal line refer to the diameter of the rollers; the entries in the table give the pressures in lbs. per sq. in.; on the layer of bagasse for distances from the line of nearest approach for rollers of the diameter indicated. An example of the calculation of one case is given. Let the diameter of the roller be 36 inches and let 1 be one inch then

$$d = 18 - \sqrt{18^2 - 1^2} = 18 - \sqrt{323} = 18 - 17.9722 = .0278.$$

Now as a basis of calculation k, the distance between the rollers at the line of nearest approach, was taken as .250; whence

$$H = k + 2\,d = .250 + .0556 = .3056.$$

The pressure required to compress the bagasse to this height is given by the equation

$$H^5\,P = 9.5 \text{ or}$$
$$P = 9.5 \div (.3056)^5 = 3606$$

That is to say the pressure on the layer of bagasse 1 inch distance from the line of nearest approach is 3606 lbs. per sq. in.

Pressure on bagasse in passage between rollers for different distances from line of nearest approach for different diameters of rollers; the calculation refers to 100,000 lbs. of cane containing 12% fiber, in a 78" mill moving at a surface speed of 25 feet per minute:

Distance from line of nearest approach.	DIAMETERS OF ROLLERS—INCHES.							
	30	32	34	36	38	40	42	44
	Pressure—Lbs. per square inch.							
0	9700	9700	9700	9700	9700	9700	9700	9700
.2	9197	9233	9253	9280	9302	93.19	9337	9355
.5	7029	7197	7289	7401	7519	7589	7689	7752
.7	5247	5422	5514	5744	5938	6016	6176	6316
1.0	2971	3177	3371	3552	3733	3905	4061	4211
1.2	1977	2131	2208	2415	2575	2707	2917	3106
1.5	925	995	1161	1256	1362	1481	1608	1754
1.7	549	632	675	801	904	1021	1047	1103
2.0	254	298	347	393	453	513	563	631
2.5	68	85	103	122	144	164	187	222
3.0	20	25	32	38	47	56	63	76

Graphic Representation of Pressure. The curves given in Fig. 16 have been drawn from the formula $H^5\,P = 9.5$ and are

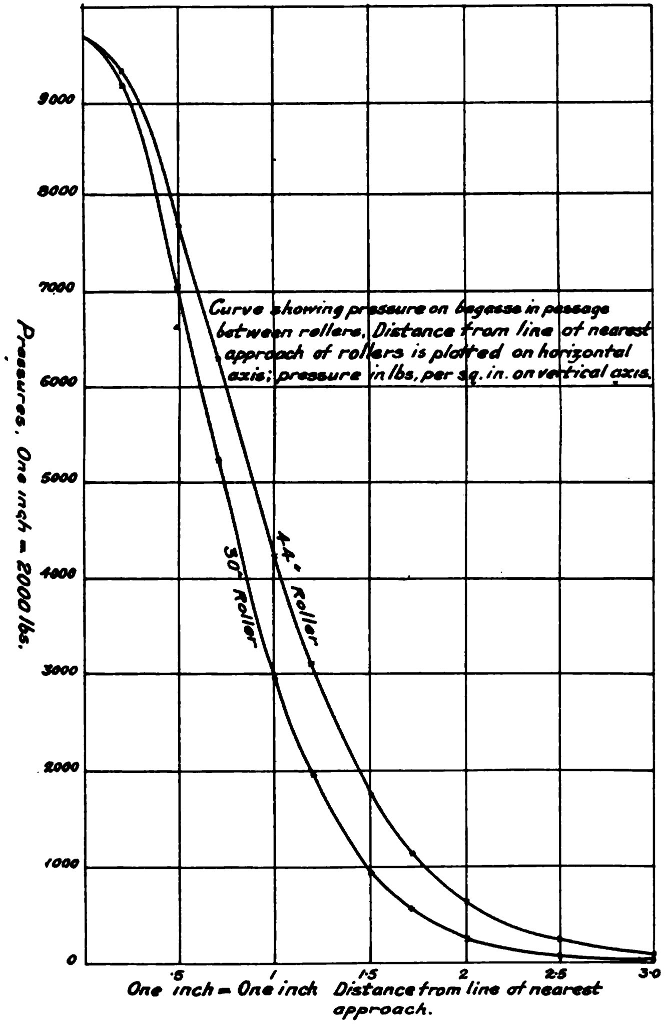

FIG. 16

referred to rollers ranging from 30″ to 44″ in diameter. Inspection of these curves shows that as the layer of bagasse is gripped by the rollers, which will take place at about 3 inches from the point of nearest approach, the pressure increases very slowly; at a distance between 1.5 and 2 inches from the point of nearest approach the pressure begins to rise very rapidly, eventually reaching a maximum of 9700 lbs. per sq. in.; it will be seen that the maximum pressure reached is independent of the diameter of the rollers but that with the larger diameter the pressure at any point except at the maximum is greater. These two curves were drawn on the assumption that the relation $H^5 P = 9.5$ held for all pressures; actually this law is only true for pressures over 500 lbs. per sq .in. In Fig. 17 is given the curve of $H^5 P = 9.5$ for a 34″ roller as far as $H = 1.7$; the remaining points on the curve were taken from the actually observed results in the table on page 21; it will be seen that this substitution makes only a small difference in the area of the curve.

Estimation of Total Pressure on a Roller. Before proceeding to the evaluation of the total pressure acting on the roller due to the passage of the layer of bagagsse the actual region of pressure must be settled. If bagasse was a material such as compressed air which would recover its original volume very rapidly as the pressure decreased the pressure on both sides of the line of nearest approach of the rollers would be identical; it was observed, however, that bagasse was a very inelastic material which recovered from the deformity due to great pressures very slowly, and also it was observed that the pressures were great enough to compress the fiber beyond the elastic limit so that when the bagasse expanded on the pressure being released it did not reach its original volume; now a speed of 25 feet per minute which was adopted as standard corresponds to a movement in the layer of bagasse of five inches in one second so that in one second the bagasse has passed through the region of pressure; from the observations made on the expansion of bagasse in the pressure pot when the pressure was released the writer is of the opinion *that the pressure due to the expanding bagasse on the discharge side is so small compared with that on the feed side that it may be neglected.* The pressure exerted on a roller by the bagasse in its passage will then be taken as that due to the layer of bagasse on the feed side only.

Referring to the curves shown in Fig. 16 the total pressure acting on the roller will be known when the area of the curve has been evaluated; the mean ordinate of the curve, that is to say the area divided by the base, will give the mean pressure. The area of the curve can be found since its equation, namely $H^5 P = C$ is known. For very much help in the mathematical analysis below I am indebted to Mr. P. V. Ceresole, formerly Assistant Professor of Applied Mathematics at the Zurich Polytechnic:

Curve connecting pressure on bagasse & distance from line of nearest approach for a 34" roller Pressure in vertical axis & distance from line of nearest approach on horizontal axis.

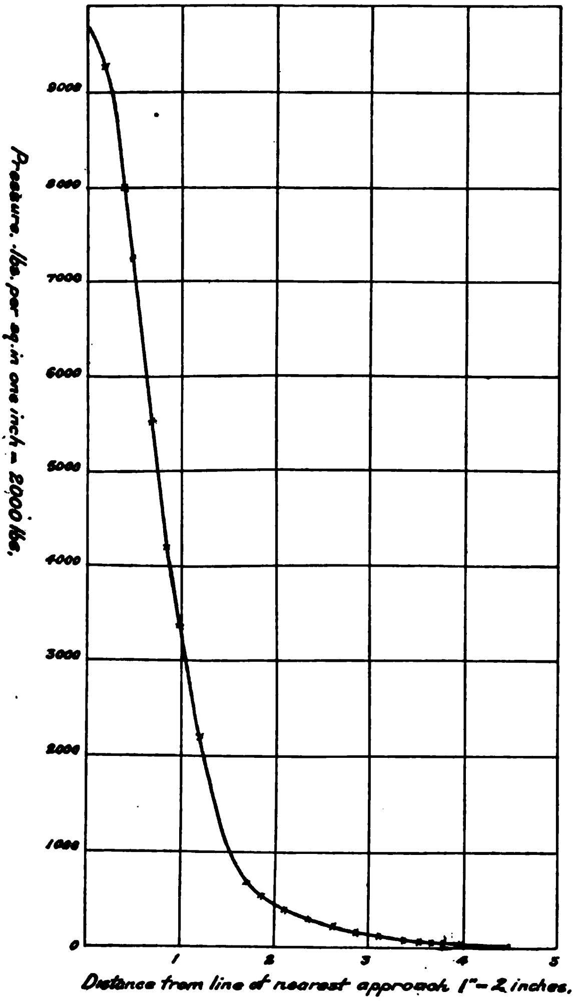

FIG. 17

Let $H^5 P = C$

But $H = k + 2r - 2\sqrt{r^2 - l^2}$

$$= k\left(1 + \frac{2r}{k} - \frac{2r}{k}\sqrt{1 - \frac{l^2}{r^2}}\right)$$

But $\sqrt{1-\frac{l^2}{r^2}} = \left(1-\frac{l^2}{r^2}\right)^{\frac{1}{2}} = 1 - \frac{1}{2}\frac{l^2}{r^2} + \frac{1}{8}\frac{l^4}{r^4} - \frac{1}{16}\frac{l^6}{r^6} +$

....

since $\frac{l}{r}$ is small terms less than $\frac{l^2}{r^2}$ may be neglected.

Then $\quad H = k\left(1 + \frac{l^2}{k\,r}\right)$

Therefore $P = \frac{C}{k^5} \cdot \frac{1}{\left(1 + \frac{l^2}{k\,r}\right)^5}$

Then the area of the curve between the limits a and b =

$$P_a^b = \int_a^b p\,d\,l = \frac{C}{k^5}\int_a^b \frac{d\,l}{\left(1 + \frac{l^2}{kr}\right)^5}$$

Let $\frac{l}{\sqrt{k\,r}} = u$

Then $d\,l = \sqrt{k\,r}\;d\,u$

$$P_a^b = \int_a^b P\,d\,l = \frac{C\sqrt{r}}{k^{\frac{9}{2}}}\int_\alpha^\beta \frac{d\,u}{(1 + u^2)^5}$$

Where $\alpha = \frac{a}{\sqrt{k\,r}}$ and $\beta = \frac{b}{\sqrt{k\,r}}$

The evaluation of $V_5 \displaystyle\int_\alpha^\beta \frac{d\,u}{(1 + u^2)^5}$

can be obtained as under

Let $A = \tan^{-1}\alpha$

$B = \tan^{-1}\beta$

$L = \alpha^2 + 1$

$M = \beta^2 + 1$

$$\text{Then } V_5 = \int_\alpha^\beta \frac{d\,u}{(1 + u^2)^5}$$

$$V_4 = \int_{a}^{\beta} \frac{d\,u}{(1 + u^2)^4}$$

$$V_3 = \int_{a}^{\beta} \frac{d\,u}{(1 + u^2)^3} \qquad \text{etc.}$$

$$V_1 = \int_{a}^{\beta} \frac{d\,u}{1 + u^2}$$

$$V_1 = \tan^{-1}\beta - \tan^{-1} a$$
$$= B - A$$

Then in succession.

$$V_2 = \frac{1}{2}\left(\frac{a}{L} - \frac{\beta}{M}\right) + \frac{1}{2}(B - A)$$

$$V_3 = \frac{1}{4}\left(\frac{a}{L^2} - \frac{\beta}{M^2}\right) + \frac{3}{4}V_2$$

$$V_4 = \frac{1}{6}\left(\frac{a}{L^3} - \frac{\beta}{M^3}\right) + \frac{5}{6}V_3$$

and

$$V_5 = \int_{a}^{\beta} \frac{d\,u}{(1 + u^2)^5} = \frac{1}{8}\left(\frac{a}{L^4} - \frac{\beta}{M^4}\right)\frac{1}{8}V_4$$

Finally

$$P_a^b = \int_{a}^{\beta} P\,d\,l = \frac{C\sqrt{r}}{k^{\frac{2}{2}}}\,\frac{1}{8}\left(\frac{a}{L^4} - \frac{\beta}{M^4}\right) + V_4$$

In taking the area of the whole curve $0 = a$, and all terms containing a disappear. This is the complete solution, but actually it is more convenient to employ graphic methods.

Referring to the case of a 34″ roller (Fig. 17) the area of the curve is found by actual measurement, when drawn to a scale of 1″ = 1000 lbs. and 1″ = 1″ to be 9.34 sq. ins.

The length of the base is 4.5 inches and hence the mean ordinate is 2.075 inches, corresponding to a pressure of 2075 lbs. per sq. in. The width of the strip of bagasse under pressure is 4.5

inches and its length is 78 inches. The total pressure is then $2075 \times 78 \times 4.5 = 728{,}000$ lbs. $=$ 364 tons.

It is interesting to compare this pressure which represents the total load on the layer of bagasse in its passage between the top and back roller in one of the later mills of a train with the actually known pressures due to the hydraulic load as used in practice. In Fig. 8 if 2 a be the apical angle of a mill on which is applied the vertical load P the resolved load along the line joining the centers of the top and back rollers is P cos a.

In actual practice in these islands P varies from 350 tons to 500 tons and 2 a varies from 72° to 84°; the table below gives values of P cos a within these limits.

P Tons	Apical angle 2 *a*						
	72	74	76	78	80	82	84
	P cos *a*						
350	283	279	276	272	268	264	260
375	302	300	295	291	287	283	279
400	324	320	315	311	306	302	297
425	344	340	335	330	326	321	316
450	364	300	355	350	345	340	335
475	384	380	375	369	364	359	353
500	405	400	394	388	383	377	372

It will thus be seen that the deduced pressure of 364 tons lies within the limits of P cos a and corresponds to the higher values; it would appear perhaps that in the experiments the pressure has been slightly overestimated or that the estimate of .25 inch as the distance between the line of nearest approach was too low.

Effect of Curvature of Rollers on Pressure. If the layer of bagasse entering the rollers be treated as a wedge neglecting the curvature of the rollers entirely different and erroneous results are obtained. Treating the bagasse as a wedge the ratio of H to 1 remains constant; to show the effect of curvature I calculated the pressure on a layer of bagasse under the standard conditions for a ratio of $\frac{H}{1} = .135$, for a length 1 from 0 to 3 inch taking k as before .250 inch and using the formula $H^5 P = 9.5$ as before. The results are given in the appended table and are also plotted in a curve in Fig. 18.

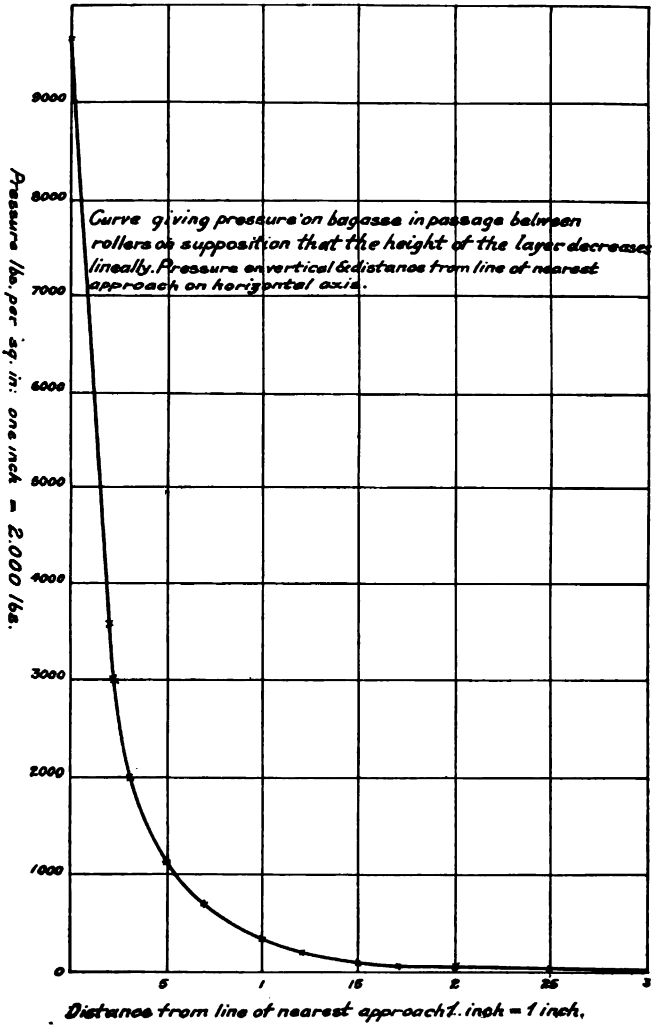
Curve giving pressure on bagasse in passage between rollers on supposition that the height of the layer decreases lineally. Pressure on vertical & distance from line of nearest approach on horizontal axis.
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
5
1
15
2
25
3
Pressure lbs. per sq. in: one inch = 2.000 lbs.
Distance from line of nearest approach 1. inch = 1 inch.

FIG. 18

L	P
0	9700
.2	3580
.5	1109
.7	700
1.0	236
1.2	175
1.5	55
1.7	53
2.0	31
2.5	14
3.0	7

Comparing these results with those in the tables on page 42 and shown graphically in Fig. 17 it is seen that the pressure drops very much more rapidly than when the curvature of the rollers is taken into account and also if the area of the curve be taken it will be found that there is no close agreement between total pressure and that calculated from the actual conditions.

Work Done in Compressing Bagasse. The general equation connecting the volume of bagasse or of cane fiber and pressure has already been found to be:

H^5 P = 9.5 when H is the height of the column or layer of bagagsse under pressure referred to standard conditions already stipulated and P is expressed in lbs. per sq. in.

In Fig. 19 is given the curve of H^5 P=9.5; consider the case of the column of bagasse on a base of 1 sq. in, and .6 inch high at which point let pressure begin. The area of this curve is given by

$$\int_{.25}^{.6} 9.5\ H^{-5} = \frac{9.5}{1-5}\left(.6^{1-5} - .25^{1-5} \right)$$

$$=590.1$$

since on the vertical scale 1 inch represents 1000 lbs. With the scale to which Fig. 19 was drawn* 1 sq. in. represents the work done by a pressure of 1000 lbs. per sq. in. in acting through .1 inch or 100 inch pounds. The work done in compressing the bagasse is then 590.1 inch pounds, or 49.2 foot lbs. Under the standard conditions (page 8) 23,400 square inches of bagasse were compressed from .6 inch to .25 inch so that the work done is 49.2 x 23400 = 1151280 ft. pounds. This is the work done in one minute corresponding to $\frac{1151280}{33000}$ =35 H. P.

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* Illustration reduced one-half.

This estimate of course refers only to the work done in actual compression of the fiber; the power developed will be largely in excess of this due to that used in the friction in the trash turner,

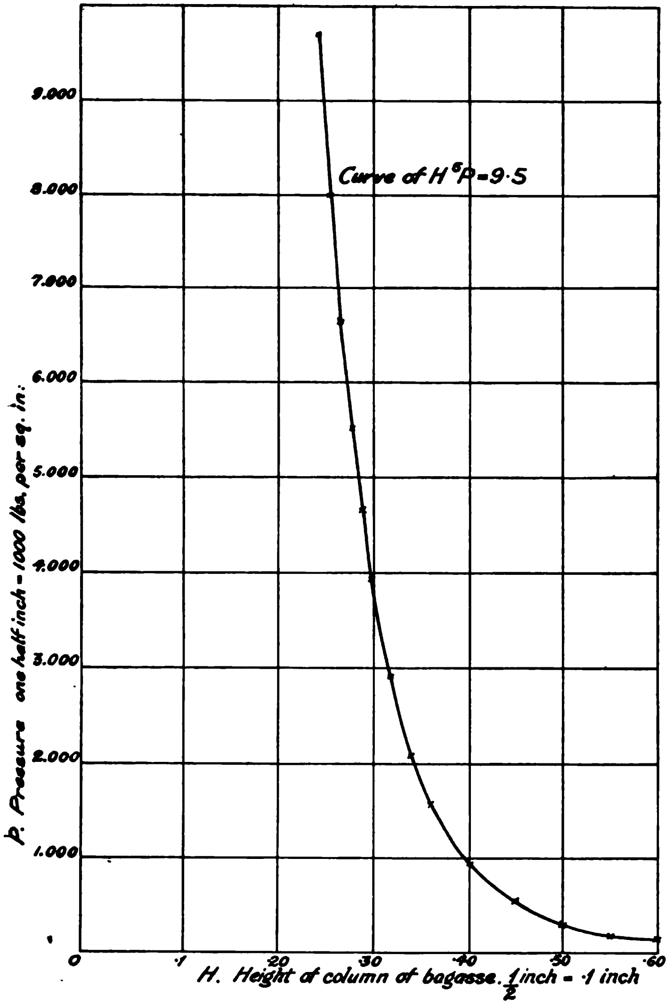

FIG. 19

in the journals and also of course a small amount of power is used in the compression between the top and front roller; it would be interesting to compare the actual work done in compression with that expended as thereby a measure of the efficiency of a cane mill as a machine would be obtained; so far as I am aware data is wanting on this matter; actually if C = work done in compression of the fiber and W = work done by the engine $\frac{C}{W}$ = efficiency.

In the above calculation of the work done in compression bagasse it has been assumed that work done is the same as if the bagasse were compressed directly under such conditions that its volume decreased lineally; in a rolling mill the rate at which the volume decreases has already been given; the work done in compression is independent of the way in which compression is applied; for the exact proof of this I am indebted to Mr. Ceresole.

In Fig. 20 let n = the specific normal pressure on a small particle of bagasse and let it be the specific tangential pressure causing uniform motion of the particle.

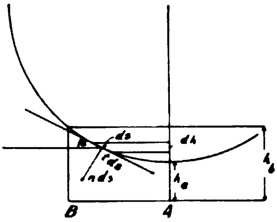

FIG. 20

Then the condition of equilibrium of the piece of bagasse A B is

$$\int_A^B t\, ds \cos a = \int_A^B n\, ds \sin a$$

Since a is small $\cos a = 1$, and

$$\int_A^B t\, ds = \int_A^B n ds \sin a$$

But since $ds \sin a = dh$

$$\text{Therefore} \int_A^B t\, ds = \int_{h_a}^{h_b} n\, dl$$

If v is the peripheral speed of the roller the work done in a unit of time is

$$w = v \int_A^B t\, ds = v \int_{h_a}^{h_b} n\, dl$$

$$= \frac{C\, v}{4} \left(\frac{1}{h_a^4} - \frac{1}{h_b^4} \right)$$

Numerical Connection Between Fiber Percent in Bagasse, Tonnage Milled Hourly and Horse Power. The general equation developed above expressive of the work done in compressing bagasse may be used to solve a number of interesting problems occurring in the practice of milling. In the case of H = .25 inch referred to 100,000 lbs. of cane containing 12% fiber per hour let it be taken that this bagasse contains 50% fiber; this selection is entirely arbitrary and represents exceptionally well crushed material; if instead of H = .25 we put H = .20 and calculate the work done we find

$$\int_{.20}^{.60} 9.5\ .20^{-5} = \frac{9.5}{1-5}\left(.60^{1-5} - .20^{1-5}\right) = 1467 \text{ inch lbs.}$$

corresponding to an expenditure of 87 H. P. Similarly the maximum pressure to which the layer of bagasse will be subjected can be found by solving the equation

$$P = \frac{9.5}{.25}$$

whence P = 29687 lbs. per sq. in. The percentage of fiber in a column of bagasse .20 inch high can be found if the composition of a column at any height is known by the use of the relation R + J = C experimentally found and described on page ...

Let the column of bagasse .25 inch high contain 50% fibre and 50% juice and consider a column standing on a base of 1 sq. in. then in this volume of material there are contained .00855 lb. fibre and .00855 lb. juice; let the height of the column of bagasse be decreased to .20 inch; then .05 c. in juice will be expressed. If the specific gravity of the juice be taken as 1.03 one cu. in. weighs .037 lb.; there is hence expressed .00185 lb. of juice and the composition of the bagasse is .00855 lb. fibre and .00670 lb. juice or 56.0% fibre and 44.0% juice.

In the annexed table I have calculated out for values of H from .20 to .30 the maximum pressure, (i. e., the pressure at the line of nearest approach) the horse power and the percentage of fiber in the bagasse all as before being referred to 100,000 lbs. of cane per hour:

Height of column of bagasse—Inches H.	Pressure at line of nearest approach.	Horse power necessary.	Fiber % in bagasse.
.20	29700	87	56.0
.21	23200	71	54.6
.22	18300	59	53.4
.23	14700	49	52.2
.24	11900	41	51.1
.25	9700	35	50.0
.26	7990	30	49.0
.27	6590	25	47.9
.28	5500	22	46.9
.29	4610	19	46.0
.30	3910	16	45.1

In considering the results shown in this table it must be remembered that they are only relative, that is to say, they are based on an assumed composition of bagasse for one particular value of H whence all the other values followed; in addition in the experiments connecting volume of fiber and pressure the highest pressure reached was 11940 lbs. per sq. in. and the relation $H^5 P = C$ is known to be true only so far; with higher pressures the exponent must increase and any increase within the limits of the table under discussion would increase the quantities tabulated in the second and third columns.

The reverse calculations, namely to find the composition of the bagasse when the tonnage of cane treated varies and the horsepower remains constant follows readily. As a basis of calculation let it be taken that with a certain horsepower available 100,000 lbs. of cane with 12% fibre are crushed so that H = .25 inch and the bagasse contains 50% of fibre; let the quantity of cane be doubled the horsepower available remaining the same; the composition of the bagasse is required. Let x be the value assumed by H under the new conditions.

$$\text{Then } \frac{2^5 \times 9.5}{1-5} \times (1.2^{-4} - x^{-4}) = 5.901$$

$$x = .602$$

That is to say the bagasse will be of a height .602 at the line of nearest approach.

This height corresponds to a height of .301 inch when the quantity of cane milled is 100,000 lbs. per hour at which height (cf table on page 21) the bagasse contains 45.1% of fibre; it is thus seen that large increases in the tonnage of cane milled are accompanied by comparatively small decreases in the fibre content of the bagasse, the power available remaining unchanged.

Direction of Resultant Force in a Three Roller Mill. In Fig. 21 let the circles represent the three rollers of a conventional three roller mill; let it be assumed that the pressure due to the bagasse acts along the lines joining the centers of top and front roller and top and back roller.

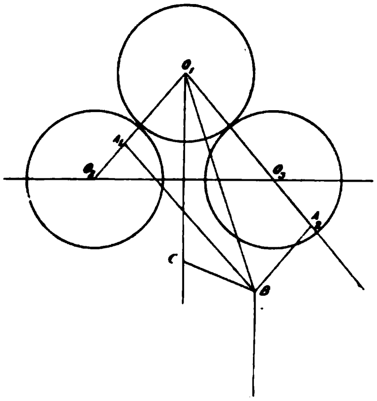

FIG. 21

Along 0_1 0_2 set off a distance 0_1 A_1 proportional to the pressure exerted by the bagasse in its passage between the top and front roller; along 0_1 0_3 set off 0_1 A_2 proportional to the pressure exerted by the bagasse in its passage between the top and back roller; through A_2 draw a parallel to 0 A_1 or through A_1 draw a parallel to 0 A_2; let these lines meet at B; then 0_1 B represents in magnitude and direction the resultant line of action of the pressure due to the passage of the bagasse; 0_1 B may then be called the position of *No Side Thrust* for if the hydraulic pressure be applied along this line no side thrust will result from the passage of the bagasse between the rollers.

If, however, the conventional symmetrical design of mill headstock be considered the magnitude and direction of the side thrust can be thus obtained. From 0_1 draw 0_1 C in the direction in which the hydraulic pressure is applied and set off 0_1 C equal in magnitude to this pressure; then B C represents the side thrust in magnitude and direction.

This is the general construction in its simplest form whence passage may be made to a consideration of the actual condition as deduced from the experiments already described. A typical setting for one of the latter mills in a train is—front opening .625 inch, back opening iron to iron; with 100,000 lbs. cane passing in one hour at 25 feet per minute in a 78″ mill the line of nearest approach of top and back roller was taken as .25 inch, corresponding to a maximum pressure of 9700 lbs. per sq. in. and to a mean pressure of 2075 lbs. per sq. in. over the whole region of pressure. With an opening of .25 inch at the back roller under working conditions the front opening becomes .875 inch; referring to the results tabulated on page .. it will be seen that a height H of .935″ corresponds to a pressure of

83 lbs. per sq. in. and a height of .710″ corresponds to a pressure of 162 lbs. per sq. in. Let it be taken that a pressure corresponding to a height of .875 inch is 100 lbs. per sq. in.; this is then the maximum pressure on the bagasse in its passage between the top and front roller; the mean pressure over the whole region of pressure will be much less; let it be taken as 50 lbs. per sq. in. then on following the construction to obtain the position of the line of no side thrust it will be seen that under the accepted condition (see Fig. 22) this line is deflected only a trifle from the line joining the centers of the top and back rollers; that is to say the pressure exerted by the layer of bagasse in its passage between the top and front roller is so small in comparison with that exerted in its passage between top and back roller that it may be neglected in so far as the line of no side thrust is concerned.

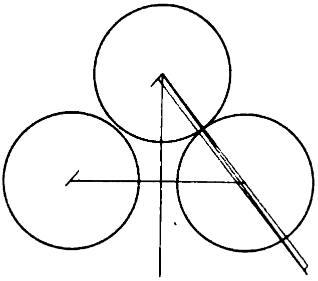

FIG. 22

Effect of Elasticity of Bagasse on the Position of the Linc of No Side Thrust. The above construction for the determination of the position of the line of no side thrust assumes that the pressure due to the layer of bagasse acts along the line joining the centers of the rollers; on page 44 reasons were given for believing that the pressure exerted by the layer of bagasse after it has passed the line of nearest approach of the rollers is negligible. The direction of the line of no side thrust its magnitude and the point of application may be obtained by the following graphic construction.

In Fig. 24 the arc represents a part of the circumference of a roller of 34″ diameter; the point 0 being a point on the line of nearest approach. Let the pressure due to the layer of bagasse be considered as uniform on strips ¼″ wide for the standard conditions; then these pressures may be obtained from the curve in Fig.. 17, and they act normal to the circumference of the roller, that i sto say along the radii.

Then the construction to obtain the resultant of these pressures is as follows: The points 1, 2, 3, etc., are the mid-points of the strips into which the layer of bagasse is supposed divided. From the curve Fig. 17 the pressure at these mid-points are 9380, 8280, 6340, etc., lbs. per sq. in. Along the radius from the point 1 set off the line 1, 1 to represent 9380 lbs., from the end of this linc

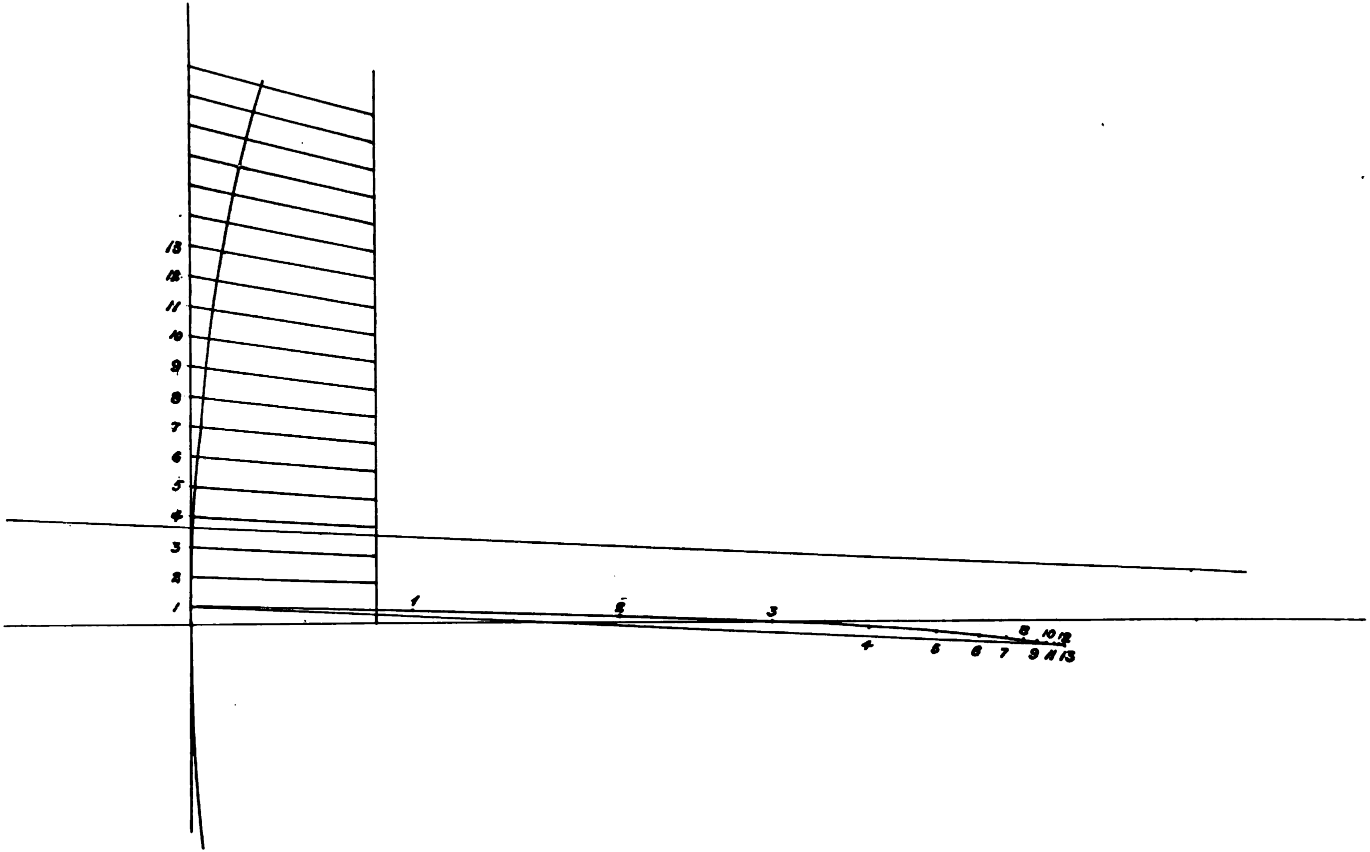

FIG. 23

draw 12 parallel to the radius; from the point 2 set off a length 23 to represent 8280 lbs.; similarly for the other strips and eventually the broken line 11234, etc., is obtained: join the initial and final point of the broken line giving the line 1, 13: this line represents in magnitude and directions the resultant of all the pressures acting on the roller; since all these forces act through the center the resultant must act also through the center; hence the point of application of the resultant is obtained by drawing a line through the center parallel to 1, 13: let this line be R R: by measurement R R cuts the circumference .810 inch from the line of nearest approach of the rollers. That is to say in a mill working under the adopted conditions the resultant line of action of the forces acting on the top roller passes through the center of the top roller and cuts the circumference at a distance of .810 inch from the line of nearest approach of the top and back roller.

Referring again to Fig. 23 and scaling off the line 1, 13 it was found to be 7.25 inches long; the scale adopted* was 1″ = 5000 lbs. and it represents therefore a pressure of 36250 lbs. on a strip .25 inch wide and 78 inches long; the total pressure then is 36250 x 78 x .25 lbs. = 343 tons; on page .. by taking the area of the curve a total pressure of 364 tons was obtained; the difference is of course due to errors of approximation in obtaining the area of the curve and in the construction of the force polygon.

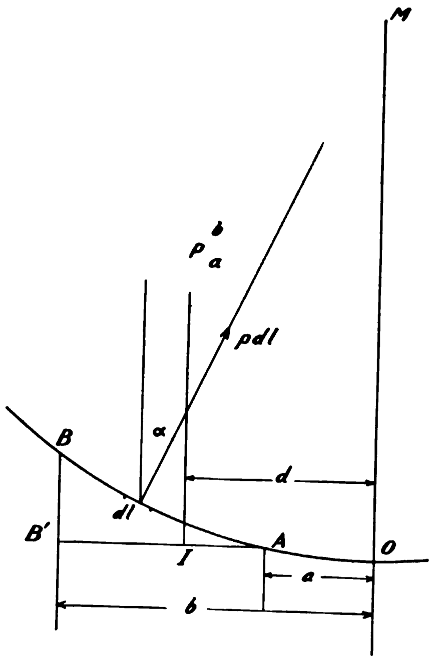

FIG. 24

The position of the line of no side thrust may also be obtained by analytical methods thus: Since each elementary force acting on the circumference of the roller passes through the center the resultant must also pass through the center. Another point on P_a^b (Fig. 24) may be obtained if, since a is small, all the elementary forces are considered as parallel to each other and parallel to O M.

---

* Illustration is not drawn according to this scale.

The point I in which the resultant P_a^b intersects the parallel A B′ to the tangent at O may be determined by its distance d from O M, since from the theory of moments.

$$d = \frac{\int_A^B p.\, dl.\, l}{\int_A^B p.\, dl}$$

The divisor in this equation has already been found and is the force P_a^b

To obtain the numerator we have

$$\int_A^B p.\, l.\, dl = \frac{C}{k^5} \int \frac{l\ dl}{\left(1 + \frac{l^2}{kr}\right)^5}$$

Putting $u = 1 + \frac{l^2}{kr}$

$$du = \frac{2\, l\, d\, l}{kr}$$

$$l\, d\, l = \frac{kr}{2}\ du$$

$$\int_A^B p\, l\, d\, l = \frac{C}{k^5} \cdot \frac{kr}{2} \int_A^B \frac{d\, u}{u^5}$$

$$= \frac{r\, C}{2k^4} \left(-\frac{1}{u^4} \cdot \frac{1}{4} \right)$$

Replacing u by $1 + \frac{l^2}{kr}$

$$\int_A^B p\, l\, d\, l = \frac{r\, C}{2k^4} \cdot \frac{1}{4} \left\{ \frac{1}{\left(1 + \frac{a^2}{kr}\right)^4} - \frac{1}{\left(1 + \frac{b^2}{kr}\right)^4} \right\}$$

and since P_b^a is known the distance d is capable of calculation.

Summary. The experiments described and developed in the preceding pages are summarized below:

1. The amount of juice expressed from chopped cane subjected to a direct pressure increases with the degree of fineness of the material.

2. After chopped cane has been pressed to a certain pressure a further notable quality of juice can be obtained by releasing the residue from pressure and pressing again.

3. The pressure at which juice begins to flow from bagasse is not a measure of the pressure at which it has been pressed.

4. With the pressure remaining constant greater percentages of juice are obtained from chopped cane as the quantity of material under pressure decreases.

5. With chopped cane the sum of the volumes of expressed juice and residue remains constant.

6. At pressures up to 60 lbs. per sq. in. the volume of bagasse varies inversely as the 2.5th root of the pressure.

7. At pressures from 500 lbs. per sq. in. to 12000 lbs. per sq. in. the volume of bagasse varies inversely as the 5th root of the pressure.

8. The quantity of juice obtained from chopped cane varies as the 12th root of the pressure.

9. It is not to be supposed that the relations formulated in 6, 7, 8 above are of the same degree of exactness as the $P V = C$ law for gases or any fundamental physical law: actually the exponent in the equations increases as a function of the pressure: at the higher pressures the increase is however very slow and the simpler expression may be used to develop a theory of the strains and stresses in the three roller mill.

10. The pressure exerted by the layer of bagasse in its passage between the top and front roller of a standard three mill is small compared with that exerted in its passage between the top and back roller, and probably amounts to about one-fortieth, with settings such as are in common use.

11. The line of no side thrust in a three roller mill of standard design is only a little deflected from the line joining the centers of the top and back rollers.

12. From consideration of the equation $H^n P = C$, the pressure on the trash turner, the power therein absorbed, the pressure on the rollers, the power required to compress bagasse, etc., can be calculated either by analytical or by graphic methods. It is to be distinctly understood that all these calculations are relative and that the accuracy of the numerical results arrived at depend on the accurate determination of the value of $H^n P$ for

one particular set of conditions; in other words, "if the power required to compress t tons of fibre in one hour to a volume V is p then the power required to compress t′ tons of fibre in one hour to a volume V′ is p′ as deduced from consideration of the equation of $H^n P = C$."

13. It has been shown in the preceding pages that the pressure exerted by the bagasse in its passage between the top and front roller is very much less—probably about one-fortieth—than that exerted in its passage between the top and back roller, that is to say the strain in the conventional three roller mill are symmetrical and as much metal is used in the feed side and in the front roller as in the delivery side and in the back roller. The logical application of the experiments described here would indicate that the front roller be regarded solely as a feed roller and would point to a two roller mill with a small feed roller as being the rational design for the later mills of a train.

In a two roller mill, however, the pressure exerted by the layer of bagasse will not be in a vertical line but following the construction given on page 56 will pass through a point .810 inches from the line of nearest approach of the rollers; in a mill with rollers superimposed vertically there will then be a small side thrust, due to the slow recovery of bagasse after compression.

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AGRICULTURAL AND CHEMICAL SERIES

BULLETIN No. 39

REPORT OF WORK
OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

The Influence of Molasses on Nitrification in Cane Soils

By S. S. PECK

HONOLULU, HAWAII
APRIL, 1912

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LETTER OF TRANSMITTAL.

To the Experiment Station Committee
of the Hawaiian Sugar Planters' Association,
Honolulu, Hawaii.

DEAR SIRS:—

I herewith submit for publication as Bulletin No. 39, of the Agricultural and Chemical Series, an article by S. S. Peck, entitled: "The Influence of Molasses on Nitrification in Cane Soils."

Very truly yours,
C. F. ECKART,
Director.

Honolulu, February 2, 1912.

THE INFLUENCE OF MOLASSES ON NITRIFICATION IN CANE SOILS.

By S. S. Peck.

In Bulletin No. 34, Agricultural and Chemical Series, this Station reported results of experiments dealing with the effect of molasses additions on the transformation of nitrogen in soils, when the nitrogen was added as sulphate of ammonia, nitrate of soda, or inorganic forms as peptone. These experiments were conducted either by measuring the changes effected in definite solutions, or in small quantities of soil kept under constant conditions of temperature and moisture. It was found that molasses accelerated denitrification and nitrogen fixation, but retarded ammonification and nitrification. The conclusions reached from the data obtained in these investigations were: 1. Molasses applied at intervals upon land on which cane is growing and fertilizer has been applied will work harm by destroying nitrates already supplied or by preventing the formation of nitrates from other sources of nitrogen supplied in the fertilizer. 2. Molasses applied to land lying fallow or at an interval of several weeks prior to the planting of the crop may produce beneficial results by providing a stimulus to the nitrogen-fixing bacteria of the soil and thereby adding a store of nitrogen to the soil in a form which can be made readily available to the crop at a later date by the other organisms in the soil. It was cautioned that the results should be accepted with some reservation, since all the conditions were exaggerated considerably over those which exist under cultural conditions in the cane fields. The conditions in lysimeter experiments, however, approach more closely to those of field practice and the experiments reported in this Bulletin were planned with the object of comparing the results with those obtained in the previous tests. In addition other experiments and more complete analyses of drainage waters were performed, with the idea of obtaining a more thorough record of the action of molasses in soils.

SOIL USED.

The soil employed was taken from the surface ten inches of the Experiment Station field. A sufficient amount was gathered to more than fill twenty-four lysimeters. These lysimeters were the same as were used in obtaining data for Bulletin No. 37, Agricultural and Chemical Series. They are made of galvanized iron, painted inside with asphalt paint. Each lysimeter is two feet in height by eight inches in diameter, the bottom being perforated with small openings. A piece of coarse sacking, above which was three inches of sand, held the column of soil. The soil was sifted through a sieve with quarter-inch openings. Forty pounds were sufficient to fill a lysimeter to within a distance from the top convenient for applying the water. The soil at the time of filling contained 11.13 per cent of water, and was slightly alkaline to litmus. The following are the figures obtained by the usual method of soil examination:

Mechanical Analysis.

Loss on ignition	20.53
Coarse grits	8.01
Fine grits	4.59
Coarse sand	2.88
Medium sand	8.97
Fine sand	25.13
Coarse silt	13.17
Fine silt	14.76
Clay	1.96

Agricultural Analysis.

Soluble silica	23.48
Insoluble silica	19.40
Iron oxide Aluminum oxide	36.77
Manganese oxide	.34
Lime	1.88
Magnesia	4.82
Potash	.16
Soda	.15

Phosphoric oxide	.77
Sulphuric oxide	.24
Chlorine	.01
Organic and volatile matter	11.51
Nitrogen	.18
Soluble in One per Cent Aspartic Acid Solution.	
Lime	0.156
Phosphoric oxide	0.0087
Potash	0.0403

In Giltay's solution, 10 grams of soil reduced the nitrate content from 24.6 milligrams per 100 cc. to 5.2 milligrams in two days; twenty-four hours later all the nitrate nitrogen had disappeared. The same amount of soil produced in a 1 per cent peptone solution 161 milligrams of ammonia nitrogen after a lapse of nine days. In Omelianski's ammonium sulphate solution, 6 milligrams of nitric nitrogen were formed in four weeks; and in a 1½ per cent mannite solution, 8 milligrams of nitrogen were fixed in 21 days. On beef agar there were developed organisms at the rate of 2,300,000 per gram of dry soil. The Station soil is an extremely fertile one, and the regular treatment it receives tends to conserve its fertility. The number of organisms shows it to be well supplied with bacterial life, and the biochemical changes recorded demonstrate that the four phases of nitrogen transformation are well represented by their respective micro-organisms. The alkaline reaction is favorable to the functioning of the beneficial bacteria, especially as regards those concerned with nitrification.

PLAN OF EXPERIMENTS.

The series comprised twenty-four lysimeters. Six acted as checks on the respective treatments; to the balance, nitrogen was added at the rate of 100 pounds per acre. The nitrogenous dressings are indicated below:

Nos. 1, 7, 13, 19.	Nothing.
" 2, 8, 14, 20.	Nitrate of soda.
" 3, 9, 15, 21.	Sulphate of ammonia.
" 4, 10, 16, 22.	High grade tankage.
" 5, 11, 17, 23.	One-third each as nitrate, sulphate of ammonia and tankage.
" 6, 12, 18, 24.	

In Nos. 6, 12, 18 and 24, lime carbonate was thoroughly incorporated with the surface three inches of soil.

Series 1 to 6, inclusive, were irrigated with water alone. In series 7 to 12, inclusive, at each irrigation there was added the ash equivalent of 40 gallons of molasses per acre-foot of 3,000,000 pounds. In series of 13 to 18, inclusive, at each irrigation molasses at the rate of 40 gallons per acre-foot was added. In series 19 to 24, inclusive, molasses at the rate of 400 gallons per acre-foot was applied one week before the first irrigation.

The molasses used was of the following composition:

Nitrogen	0.27%	Potash	5.68%
Silica	0.28	Soda	0.65
Iron and alumina	0.04	Sulphuric oxide	1.58
Lime	0.84	Phosphoric oxide	0.18
Magnesia	0.99	Chlorine	3.66

It was, of course, impossible to accurately duplicate the inorganic ash of the molasses, since some of the bases are combined with organic acids. It was desired, however, to approximate as close as possible to the mineral contents, and a solution was prepared of such strength that 10 cubic centimeters represented the ash of 3 grams of molasses, this being the amount apportioned to a lysimeter to represent 40 gallons of molasses per acre-foot. The molasses ash was, for this purposes, assumed to be composed as follows:

Potassium chloride	7.69%
Potassium sulphate	1.53
Magnesium sulphate	1.32
Calcium phosphate	0.40

All the inorganic acid radicals are thus represented; a considerable proportion of the magnesia and lime and all of the soda were lacking, but it is not felt that the absence of these smaller (proportionately) constituents affected the results of the experiments.

The general purpose of the experiments was as follows: To measure, by analyses of drainage waters, the amounts of nitric nitrogen produced from ammonium sulphate or tankage, under the influence (a) of a large application of molasses; (b) under the influence of the same amount of molasses, but applied in smaller amounts at regular intervals; (c) under the influence of the mineral matter of molasses applied at regular intervals; to measure the loss of any nitric nitrogen from nitrate of soda under the same conditions; to ascertain if carbonate of lime exerts a corrective influence on the adverse action of molasses, under the same conditions. Since it was impossible to measure this last effect on each form of nitrogen, on account of lack of lysimeters, the composite nitrogen series was introduced. In this series one-third of the nitrogen comes from each of the forms in the tests preceding, viz., nitrate of soda, sulphate of ammonia, and high grade tankage. There are, therefore, two such tests in each series of six, one with lime carbonate, the other without.

The weighed quantity of soil being placed in each lysimeter, sufficient water was added to each until about two liters were drained away. A week later the lime carbonate was applied to Nos. 6, 12, 18 and 24, and 30 grams of molasses dissolved in water to Nos. 19 to 24, inclusive; the same amount of water was added to each of the other tests, so as to preserve the moisture conditions as near alike as possible. At the end of another week, the fertilizing elements were stirred in the surface three inches of soil, with sufficient water for solution of the soluble elements. The first irrigation was applied one week after the introduction of the fertilizers, and repeated at intervals of two weeks until 10 irrigations had been effected. Sufficient water was used each time to give two liters of drainage. This drainage was analyzed at once for nitrogen, chlorine, total minerals and alkalinity. A quarter of the drainage water of each was evaporated to small bulk and set aside for analysis. These concentrated solutions were united at the end of the experiments and analyzed for lime, magnesia, potash, soda, sulphuric and phosphoric oxides.

It was found early that there were but small and unimportant amounts of ammonia nitrogen and only traces of nitrite nitrogen in the drainage. As in Bulletin 37, these amounts were accordingly reported along with the nitric nitrogen.

RESULTS OF THE EXPERIMENTS.

In Table I, the amounts of nitric nitrogen obtained in each leaching, expressed as milligrams of nitrogen, are given. In tests 1, 7, 13 and 19, this nitrogen comes from the organic nitrogen of the soil. In the remainder, the nitrogen originates both from the soil and 604.8 milligrams of nitrogen added in the various fertilizer forms.

TABLE I.

(Nitric Nitrogen leached at each irrigation, in milligrams.)

Irrigation No.	LYSIMETER NUMBER.											
	1	2	3	4	5	6	7	8	9	10*	11	12
1...	64.0	87.4	74.8	64.7	71.2	65.3	64.6	76.0	67.2	67.4	76.0	79.0
2...	58.5	133.0	53.2	60.2	83.7	94.4	59.9	140.1	63.1	57.3	86.0	90.7
3...	39.5	197.4	82.7	61.7	106.9	117.4	44.0	221.6	64.7	58.6	125.7	131.4
4...	43.9	156.5	146.2	105.8	122.9	145.6	42.2	147.8	127.5	89.4	134.5	145.5
5...	41.0	96.1	163.1	106.3	114.7	115.1	43.7	89.7	145.0	74.9	123.7	125.9
6...	44.5	66.2	151.2	100.7	93.4	87.4	46.9	57.7	155.0	64.8	110.2	97.7
7...	53.2	69.4	139.2	106.2	101.5	81.9	51.7	46.2	142.9	73.8	110.7	81.9
8...	52.5	47.4	79.8	79.2	77.6	63.0	53.7	51.1	89.1	41.0	59.0	60.9
9...	44.1	53.6	52.9	62.4	59.2	50.2	41.7	46.1	61.3	37.2	47.1	48.9
10...	42.8	42.0	48.2	41.8	53.8	48.3	43.1	42.6	50.6	34.3	45.5	47.0
Total.	484.0	949.0	991.3	789.0	884.9	868.6	491.5	918.9	966.4	598.7	918.4	908.9

	LYSIMETER NUMBER.											
	13	14	15	16	17	18	19	20	21	22	23	24
1...	62.2	59.3	64.3	64.6	66.5	79.3	62.9	64.8	73.4	64.8	65.1	60.1
2...	58.6	138.9	66.2	66.4	94.5	92.4	64.9	111.1	63.1	66.8	90.3	88.2
3...	45.9	236.2	84.2	65.3	121.0	116.3	33.6	167.3	85.3	54.7	100.2	90.0
4...	36.0	146.6	134.8	83.4	122.8	119.0	34.3	152.3	95.2	88.2	103.2	111.8
5...	29.4	59.7	110.9	77.6	90.5	77.1	37.5	91.4	98.0	97.2	102.4	99.0
6...	34.7	70.6	147.0	93.0	99.4	88.5	47.4	67.2	180.2	100.8	86.9	98.6
7...	30.2	36.7	103.0	71.8	69.0	70.7	42.6	51.1	130.9	94.3	72.6	80.4
8...	24.5	28.6	52.1	45.3	41.0	41.2	42.0	39.8	56.8	73.5	50.5	58.6
9...	24.4	30.9	40.5	34.1	33.3	28.6	33.9	28.7	41.4	60.1	32.4	49.3
10...	26.9	22.7	25.7	28.2	24.0	27.6	24.6	21.0	25.7	44.4	24.1	41.4
Total.	372.8	830.2	828.7	629.7	762.0	740.7	423.7	794.7	850.0	744.8	727.7	777.4

* See note, page 17.

In the next tables the amounts of total minerals and chlorine, in milligrams, removed at each irrigation are given, and the alkalinity in terms of tenth normal alkali.

TABLE II.

(Total Mineral Matter removed each irrigation, in milligrams.)

Irrigation No.	LYSIMETER NUMBER.											
	1	2	3	4	5	6	7	8	9	10	11	12
1...	1,148	1,223	1,228	1,197	1,222	1,233	1,136	1,108	1,114	1,102	1,170	1,226
2...	1,030	1,813	1,053	1,055	1,297	1,319	1,019	1,580	1,012	1,005	1,196	1,321
3...	725	1,700	1,065	966	1,193	1,300	542	1,535	713	729	1,072	1,184
4...	615	1,554	1,750	1,310	1,425	1,768	733	1,687	1,357	957	1,198	1,368
5...	623	1,130	2,015	1,210	1,336	1,387	813	1,017	1,637	693	1,193	1,438
6...	677	967	1,882	1,145	1,229	1,294	806	938	1,682	867	1,397	1,165
7...	894	934	2,009	1,518	1,601	1,452	841	1,032	1,977	1,324	1,255	1,386
8...	882	853	983	1,285	1,328	1,158	841	1,042	1,631	455	1,292	1,338
9...	849	974	1,120	1,280	1,404	1,104	852	829	1,156	960	1,034	973
10...	821	743	1,050	816	886	842	1,021	1,008	1,376	1,068	770	1,126
Total.	8,264	11,891	14,155	11,782	12,921	12,857	8,604	11,776	13,655	9,160	11,577	12,525

	LYSIMETER NUMBER.											
	13	14	15	16	17	18	19	20	21	22	23	24
1...	1,085	1,068	1,125	1,135	1,185	1,222	1,188	1,228	1,314	1,352	1,421	1,333
2...	986	1,662	977	1,358	1,440	1,422	1,483	1,889	1,472	1,523	1,452	1,444
3...	772	2,116	1,111	1,040	1,440	1,380	1,440	1,469	1,123	1,632	1,743	1,522
4...	759	1,395	1,501	1,205	1,399	1,325	1,227	1,979	1,333	1,626	1,560	1,953
5...	666	886	1,257	1,053	1,102	1,181	858	1,229	1,308	1,543	1,565	1,442
6...	949	1,057	2,316	1,726	1,823	1,711	1,201	1,132	2,616	1,094	1,269	1,139
7...	1,003	1,066	2,022	1,348	1,680	1,480	966	1,110	2,727	1,376	1,328	1,396
8...	826	1,066	1,390	1,303	1,377	1,208	831	802	1,164	1,106	1,099	1,272
9...	1,020	1,088	1,547	1,218	1,180	1,173	709	701	992	1,131	1,068	1,091
10...	896	923	704	1,142	905	968	592	534	769	757	860	957
Total.	8,962	12,327	13,950	12,528	13,531	13,070	10,495	12,073	14,818	13,140	13,365	13,549

TABLE III.

(Chlorine removed each irrigation, in milligrams.)

Irrigation No.	LYSIMETER NUMBER.											
	1	2	3	4	5	6	7	8	9	10	11	12
1...	138	136	136	134	140	138	141	138	144	141	138	138
2...	139	116	125	163	133	127	129	104	114	126	114	122
3...	110	106	96	147	118	108	126	117	99	150	122	125
4...	105	128	106	131	101	116	150	163	143	156	149	151
5...	96	120	107	106	117	112	160	168	162	110	162	175
6...	97	128	114	100	109	113	162	170	165	120	215	191
7...	132	157	154	138	146	156	206	230	243	219	238	249
8...	129	143	149	149	151	144	224	222	236	176	238	258
9...	102	115	104	137	109	102	199	190	219	228	219	217
10...	95	87	103	99	104	100	208	198	220	243	214	207
Total.	1,143	1,236	1,194	1,304	1,228	1,216	1,705	1,700	1,755	1,669	1,809	1,833

	LYSIMETER NUMBER.											
	13	14	15	16	17	18	19	20	21	22	23	24
1...	119	124	121	132	120	123	125	136	130	188	185	172
2...	132	103	120	162	126	132	299	335	271	408	372	332
3...	140	140	131	176	141	139	505	423	415	478	436	415
4...	156	181	161	188	161	165	392	422	359	420	334	402
5...	123	145	130	173	145	145	254	307	233	243	264	252
6...	179	206	207	232	211	228	200	160	323	190	192	216
7 ..	229	257	288	243	284	262	173	167	268	180	183	186
8...	209	231	267	236	271	257	142	145	125	147	146	148
9...	226	238	281	245	268	286	125	135	105	122	133	132
10...	216	201	217	228	214	228	93	105	81	97	103	108
Total.	1,729	1,826	1,923	2,015	1,941	1,965	2.308	2,335	2,310	2,473	2,348	2,363

TABLE IV.

(Alkalinity of each irrigation, as 10th normal alkali.)

Irrigation No.	LYSIMETER NUMBER.											
	1	2	3	4	5	6	7	8	9	10	11	12
1...	26	24	33	30	33	26	27	24	27	30	23	23
2...	17	15	17	19	17	17	16	14	20	16	12	22
3...	13	12	15	11	11	9	8	11	12	13	11	11
4...	10	14	9	11	9	9	7	14	9	12	10	12
5...	11	14	10	9	10	9	9	10	9	12	9	12
6...	11	12	10	10	9	8	8	10	10	14	10	12
7...	17	16	15	22	12	12	10	12	15	48	15	15
8...	18	17	18	26	15	15	13	13	17	11	38	18
9...	21	23	29	11	15	11	13	11	13	35	17	21
10...	27	24	23	36	19	17	24	18	22	42	24	27
Total.	171	171	179	185	150	133	135	137	154	233	169	173

	LYSIMETER NUMBER.											
	13	14	15	16	17	18	19	20	21	22	23	24
1...	14	18	14	20	24	20	22	22	22	24	22	27
2...	14	10	10	15	14	12	22	18	20	29	21	30
3...	15	10	13	15	13	12	16	17	21	29	17	26
4...	15	14	11	16	22	15	19	18	23	25	21	26
5...	12	9	5	13	6	7	15	14	15	16	14	10
6...	13	11	7	17	14	13	32	21	40	29	28	26
7...	15	16	14	19	29	16	35	38	61	33	47	34
8...	13	12	10	18	20	13	35	43	36	32	46	34
9...	17	19	14	24	24	17	45	48	39	34	55	42
10...	16	21	21	17	25	15	37	47	39	33	52	52
Total.	144	140	119	174	191	140	278	286	316	234	323	307

In Table V will be found the total weights of silica, lime, magnesia, potash, soda, sulphuric oxide and phosphoric oxide recovered in drainage waters.

TABLE V.

(Total weights of elements removed in grams.)

Lysimeter Number	Silica	Lime	Magnesia	Potash	Soda	Sulphuric Oxide	Phosphoric Oxide
1	586.4	930	449.8	176.2	1,163	415.6	36
2	580.8	1,405	705.7	248.7	1,214	408.1	34
3	484.0	1,670	989.4	264.6	1,327	1,730.9	32
4	540.4	1,300	673.9	242.5	1,013	585.0	34
5	552.4	1,400	580.5	251.8	1,156	785.2	32
6	530.0	1,375	692.3	242.1	1,185	866.9	32
7	520.8	1,055	511.0	202.9	963	474.6	44
8	368.8	1,470	826.6	239.4	1,117	498.6	56
9	556.0	1,865	1,032.9	277.4	1,255	1,522.5	60
10	360.0	1,315	658.7	179.6	975	447.8	90
11	514.0	1,625	834.2	229.7	1,169	920.3	62
12	509.2	1,690	901.1	271.6	1,206	977.3	80
13	539.6	1,045	472.6	177.3	979	528.1	32
14	572.0	1,470	716.6	238.6	1,134	488.3	26
15	838.4	1,875	990.9	270.4	1,254	1,510.0	24
16	626.0	1,365	699.9	241.7	1,184	587.8	28
17	595.2	1,640	878.0	257.6	1,219	994.4	28
18	523.2	1,525	780.3	239.0	1,160	922.4	24
19	574.0	1,465	771.7	246.8	1,165	729.0	56
20	468.4	1,855	960.5	269.7	1,241	707.8	56
21	527.6	2,270	1,163.1	277.0	1,388	1,772.8	24
22	530.4	2,158	860.2	279.0	1,309	795.1	55
23	336.4	1,975	1,022.0	274.3	1,336	1,001.3	94
24	527.2	1,655	1,006.1	253.0	1,381	1,172.7	86

The results will probably be better understood if given as pounds per acre-foot. On the basis of 3,000,000 pounds to the acre-foot, Table VI has been calculated from the data just given.

TABLE VI.

(Total weights of elements removed, pounds per acre.)

Lysimeter Number	Nitric Nitrogen	Lime	Magnesia	Potash	Sulphuric Oxide	Chlorine
1	80	154	74	29	66	189
2	157	232	117	41	68	204
3	164	276	164	44	286	198
4	131	215	111	40	97	216
5	146	232	96	42	130	203
6	144	227	115	40	143	201
7	81	174	85	34	79	282
8	152	243	137	40	82	281
9	160	309	171	46	252	290
10	99	217	109	30	74	276
11	152	209	138	38	152	299
12	150	279	149	45	162	303
13	62	173	78	29	87	286
14	137	243	119	40	81	302
15	137	310	164	45	250	318
16	104	226	115	40	97	333
17	126	271	145	43	164	330
18	123	252	129	40	153	325
19	70	242	129	41	121	381
20	131	307	159	45	117	386
21	141	375	192	46	293	382
22	123	357	142	46	132	409
23	120	327	169	45	165	388
24	129	274	166	42	194	391

DISCUSSION OF RESULTS.

(*a*) *Nitrogen.*

The principal object of this investigation was the study of the alterations in nitric nitrogen in soils as influenced by molasses fertilization. The conclusions in this respect are based on the assumption that the principal limiting influence, as regards nutrient material, in the growth of a cane crop in Hawaii is the available nitrogen in the soil; and that nitric nitrogen is the principal source of supply of this element to the cane. The importance of nitrogen to this crop has been repeatedly demonstrated in field trials and plantation experience. The form in which nitrogen is assimilated by the plant has usually been accepted to be in that of nitrate combination. It has recently been developed by agricultural investigators that certain crops can derive their nitrogen supply from other sources; but it is safe, with our present knowledge, to postulate that if nitric nitrogen is not the only source of nitrogen absorption by the cane, it is at least the chief source. On these premises the writer has in this Bulletin designated any treatment by which the amount of nitric nitrogen has been suffered a reduction, as being due to a harmful influence.

The molasses used in these tests contained 13 per cent of mineral matter, 52 per cent sugars, 0.27 per cent nitrogen and 20 per cent of water, the balance being composed of gums, organic acids, etc. Four series with similar nitrogen treatments and varying molasses applications were carried out, and may be defined as follows:

A—Nothing.

B—Molasses ash each irrigation, equivalent to 40 gallons of molasses per acre.

C—Molasses each irrigation, equivalent to 40 gallons of molasses per acre.

D—Molasses equivalent to 400 gallons per acre applied one week before the first irrigation; subsequent irrigations with water only.

By comparison between series B and C, it was hoped to ascertain how much of the harmful effects, if any, were due to the mineral matter of the molasses; by comparison of C and D, it was expected that some differences might be observed as to the effect of molasses applied at one time, and when applied at regular intervals, the sum total of the application being the same.

In Table VII, the amounts of nitric nitrogen in pounds per acre are compared.

TABLE VII.

(Nitric nitrogen recovered from soil nitrogen, and nitrogenous fertilizations at the rate of 100 pounds of Nitrogen per acre, in pounds per acre.)

SERIES	Nothing	Nitrate of Soda	Sulphate of Ammonia	Tankage	Three forms	Three forms and Lime Carbonate	Average**
A............	80	157	164	131	146	144	138
B............	81	152	160	99*	152	150	139
C............	62	137	137	104	126	123	117
D............	70	131	141	123	120	129	118

It is evident that in all instances the molasses worked a harmful effect, and that this effect was not due to the mineral matter, but the organic substances in the molasses. In view of the results reported in Bulletin No. 34, it is safe to say that this harmful influence was due to the sugars in the molasses. Comparison of results of series A and B shows no significant differences, the average of all figures giving an advantage of only one pound where the mineral matter of the molasses was added.

Soil Nitrogen—The most serious loss in nitrate nitrogen was shown in lysimeter 13; here, where there was no fertilizer added, and molasses at each irrigation, there were obtained 18 pounds of nitrogen, or 22.5 per cent less than where no molasses was used, although there were 13 pounds of nitrogen added with the molasses, a portion of which at least might have contributed to the nitrate content in the drainage. The molasses evidently acted as a check to the ammonification and subsequent nitrification of the organic nitrogenous soil compounds. Where the molasses was applied at one time, the injurious effects were most apparent at the third irrigation, five weeks after the application. Thereafter there was a constant rise until the sixth irrigation, followed by a drop to the minimum content at the last. The total loss amounted to 10 pounds, or 12.5 per cent less than the check. Where the smaller quantity of molasses was applied at each irrigation, there was a general drop in nitrate content from the first irrigation to the eighth, after which there was but little change. It would appear that after the disappearance of the sugars of the molasses in series D, the soil was able to regain some of its original powers of ammonification and nitrification; with fresh molasses being supplied at two weeks' intervals, these powers were continually kept in check.

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* After the third irrigation, this lysimeter, No. 10, became clogged up and refused to drain. The soil thus became water-logged and the results cannot be used.

** Excluding Tankage tests.

Nitrate of Soda—Figuring on the basis of the nitrogen obtained from the soil nitrogen as being the same under all conditions of nitrification, 77 per cent of the nitrogen supplied as nitrate of soda was recovered in the test where water alone was used, and but little less, 75 per cent, where molasses was added at each irrigation. This is to be expected, since the greater part of the nitrate recovered was leached out in the second, third and fourth irrigations, before the effect of the molasses as a denitrifying accelerator was sufficient to produce large differences. As may be seen by reference to Table I, after the fourth irrigation, both tests showed a big drop in nitrate content of drainage, which, after the seventh irrigation, was but little different from the tests where no nitrate had been applied. In series D, the nitrate solution was in contact with the heavy molasses application for seven days before irrigation and drainage was started. The denitrification processes were thus able to produce a sensible decrease in the amount of nitrate recovered, only 61 per cent of that applied passing into the drainage, or an increased loss of 14 per cent over the more frequent molasses additions.

Ammonium Sulphate—The nitrogen of this material must be converted by micro-organisms into nitrate compounds before any considerable amounts are leached from the soil. The nitrate content reached its maximum at the fifth or sixth irrigation, thereafter declining, until at the last irrigation, the nitrate content approached closely to that from the unfertilized tests. Eighty-four per cent of that added was recovered in the irrigation water where no molasses was added. Seventy-five per cent and 71 per cent were recovered, respectively, with molasses additions in repeated and single additions. The molasses has thus been responsible for the loss of from 10 to 15 per cent of the nitrogen applied as sulphate of ammonia.

Tankage—This material being much slower in its transformation into nitrate compounds, only 51 per cent was recovered after 10 irrigations with water, and 12 per cent with molasses added each time. In series D, whilst there were 8 pounds of nitrogen less recovered in all than in series A, 53 per cent of the tankage nitrogen was accounted for. It is evident that, as with the organic nitrogen of the soil, the influence of molasses on organic nitrogen, as in tankage, is more adverse the more frequent the applications.

Three Forms of Nitrogen—These tests were for the purpose of ascertaining what influence the presence of lime carbonate would have on the action of the molasses on the work of the nitrogen transforming organisms. A recent article* states, relative to the use of molasses as a fertilizer, that "the results obtained from its use on soils containing *sufficient* amounts of carbonate of lime are as good as are produced by rotation, intensive cultivation and fertilization. This is probably due to the fermentation of the molasses in the soil, which greatly assists soil renovation." We do not believe that these conclusions are generally justified. Molasses applied to land lying fallow will stimulate the activity of the nitrogen-gathering azotobacter and enrich the soil in this respect to a degree corresponding to their activities. These organisms require an alkaline medium for favorable functioning, and carbonate of lime is usually employed in the laboratory culture tests. But these organisms are aerobic, and unless the soil is well aerated, will not perform their full duties. The benefit is not derived from a renovation of the soil by the fermentation of the molasses, but from the effect of the stimulus to these organisms from the carbohydrates contained in the molasses. It is freely granted that molasses applied to soil which is lying fallow may produce an appreciable and profitable benefit, and that an alkaline reaction of the soil due to calcium carbonate is desirable; and that if instead of one week, a longer period, of say two months, had been allowed between the application of the larger quantity of molasses and the addition of the fertilizers, the results in series D of the experiments reported here might have been quite different in regard to nitric nitrogen recovered in drainage. But when the cane is growing and receiving artificial nitrogenous manures, the conditions which obtain are quite dissimilar. The expression "fermentation of the molasses" is, moreover, apt to be misleading. This would generally be supposed to refer to alcoholic fermentation. But Stoklasa and Vitek* have found that, under anaerobic conditions, alcohol will produce a reaction corresponding to the formula

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* International Sugar Journal, January, 1911, p. 29.

$$C_2H_6O + N_2O_5 = 2CO_2 + 2NH_3$$

That is, the important nitric nitrogen will be changed into ammonia, and in this shape will be lost to the plant, or necessitate a return of conditions whereby it may again be transformed back into the nitrate form. Fermentation, however, may not necessarily be alcoholic. Thus, it may refer to acetic, lactic, butyric, or viscous transformations of the carbohydrates of the molasses, according to the organism or organisms creating the transformation. It is to be observed, in a general way, that an alkaline medium is less favorable to these ferments than an acid, and from the fact that the author quoted states that the presence of carbonate of lime is essential for good results from molasses fertilization, we may conclude that the beneficial results come from the influence on the azotobacter, and not from changes in the soil induced by fermentative changes of the molasses.

Examining the figures of all four series, in Table VII, it will be seen that the four lysimeters fertilized with the three forms of nitrogen produced the same amount of nitrate nitrogen with and without the addition of calcium carbonate. Without this addition, the total amount was 544 pounds, and with the carbonate, 546 pounds. Observing the results from the molasses irrigations, the carbonate caused a slight decrease where the molasses was applied in small amounts, and an increase of 9 pounds when the molasses was given to the soil in one application. It is possible that during the seven days in which the molasses was in lysimeter 24, under the favorable influence of the calcium carbonate, that the activity of the azotobacter and the nitrogen stored up by them was sufficient to cause this decided increase. In laboratory experiments with this soil, it was found that in three weeks' time there were fixed by the soil 8 milligrams of nitrogen per gram of carbohydrate. While the increase in one week is not necessarily an arithmetical proportion, calculating on this basis, the 400 gallons of molasses should have caused the fixation of 7.6 pounds of nitrogen. On the tests where only organic nitrogen, from the soil or soil and tankage, were present, the continual addition of molasses was more harmful than when applied at one time. In the soil alone, the advantage in favor of the latter treatment amounted to 8 pounds; with a further addition of organic nitrogen in tankage, this difference increased to 19 pounds. Now when the three forms of nitrogen were supplied, the large application of molasses works more adversely than the smaller repeated applications with respect to the water-soluble forms, nitrate of soda and sulphate of ammonia, but more favorably as regards the organic form. The latter increase is not sufficient to counterbalance the loss in the water-soluble forms; but when a possible 8 pounds more of readily decomposable nitrogen is added to the soil through the stimulation of the azotobacter by the lime carbonate, an additional 9 pounds of nitrate nitrogen is received in the drainage.

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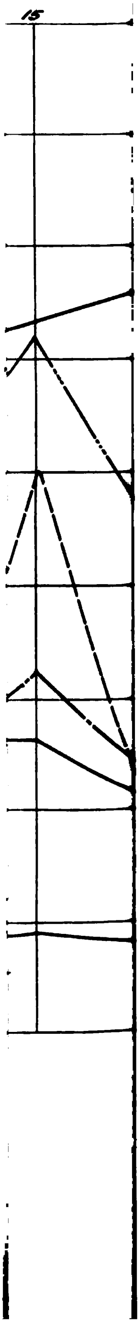
* Central Blatt. f. Bakt. 2, 1905, p. 110.

From the average figures, the conclusions to be drawn are that the ash of the molasses has no effect on the nitrification in the soil, but molasses applications reduce the formation of nitrate nitrogen by 15.2 or 14.5 per cent, when applied at the rate of 400 gallons to the acre in ten successive portions or in one application, respectively.

Mineral Matters Removed.

The proportionate amount of mineral matters removed is shown graphically on Chart 1. A fairly regular agreement occurs between the lime, magnesia, potash and soda, a rise or fall in one being generally accompanied by a like change in the remainder. In the tests receiving 100 pounds of nitrogen per acre as ammonium sulphate, a pronounced increase in the amounts of sulphuric oxide found in the drainage results, accompanied by decided gains in the other mineral matters. A lesser gain is exhibited where one-third of the nitrogen was supplied in this form, while the increase of the other minerals was correspondingly diminished. Nitrate of soda increased the lime removal considerably, but to a lesser extent than ammonium sulphate; the magnesia, potash and soda were affected in the same manner. The amounts of chlorine recovered varied naturally with the amount added in the molasses; where the molasses or molasses ash was added in small amounts, only a portion of the chlorine added was recovered; if the irrigations had been continued all would have been recovered, since in series D, where the molasses was added at one time and subjected to ten irrigations, there were found, as shown in Table VIII, an average of 171 pounds more chlorine in the waters than in those of the check tests, almost accounting for the 179 pounds added in the molasses. Of the other minerals, only the magnesia corresponded in the extra amount removed to that supplied in the molasses, being 50 pounds, as compared with 49 pounds added. There were 41 pounds of lime added, but twice as much, 81 pounds, recovered; this is explained by the action of the extra chlorine and sulphuric oxide in the soil waters of this series on the lime compounds. Of 279 pounds of potash added, only 4 pounds drained away; the well-known fixing power of Hawaiian soils of this element is again exhibited here. Of the 78 pounds of sulphuric oxide added as molasses, 40 pounds were still retained by the soil at the expiration of the experiment.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Effect of Treatments on Each Form of Nitrogen Fertilization.

For the purpose of better comparison, the results of each treatment on the added nitrogen have been drawn to scale and are given in Charts 2, 3, 4, 5, 6 and 7.

In general the changes in the amounts of the various minerals removed will be found to be very close to those pointed out in the previous discussion. Some divergences are noticed, and are naturally to be expected. Thus, in the most of the tests, a large increase in the amount of sulphuric oxide removed is noticed in the experiments of series D, where the molasses was applied in one application. An exception is noted in the experiments with ammonium sulphate, where the large amounts originating with the fertilizer partially masked the effects of molasses as regards soluble sulphates. This is also partially true in the case where ammonium sulphate supplied a third of the nitrogen; in one case, Chart 6, the amounts removed with the two forms of molasses applications were identical; in the other case, Chart 7, there was the usual evidence of increase, but not to the same extent as in the other similar tests. The general relation between the amounts of soluble lime and sulphuric oxide is well exemplified in these smaller charts. In Chart 8 and Table VIII the results of the averages from the various forms of molasses treatment are given.

TABLE VIII.

Average results, excluding tankage experiments.

	Pounds per Acre						
	Nitric Nitrogen.	Chlorine	Lime	Magnesia	Potash	Soda	Sulphuric Oxide
Check	138	199	224	113	39	200	139
Molasses ash	139	291	255	136	41	189	145
Molasses, 10 applications	117	313	250	127	39	190	147
Molasses, 1 application	118	370	305	163	43	215	178

The table and chart show that the inclusion of molasses ash with the irrigation water had no effect on the nitrifying power of the soil; that the organic matter of the molasses depressed this power very considerably; that the increase of chlorine noticed from the molasses-ash to the repeated molasses applications had but little effect on the solubility of the other mineral elements, and that, with one application of molasses, along with a decided increase in chlorine, there was a large increase in sulphuric oxide, accompanied by correspondingly larger amounts of the other mineral matters leached from the soil.

Alkalinity.

The drainage waters throughout the test reacted alkaline to methyl orange. It is indicated that in spite of the nitrification of ammonium sulphate, and the combination of the released acids with lime and magnesia, there was a sufficiency of these elements in the soil to prevent any change in the alkalinity of the soil waters. Where molasses was applied at one time, there was a decided increase in the alkalinity; in the other tests, with the exception of lysimeter 10, where the drainage was imperfect, there are but little and irregular differences to be noted. In no case did the alkalinity reach sufficiently high proportions to lead to the belief that nitrification was interfered with from this cause. The highest degree of alkalinity was noticed in lysimeter 21 after the seventh irrigation; this was equivalent to but 3.2 parts of sodium bicarbonate per 100,000 of dry soil, an amount which would scarcely produce any adverse effects.

Continued fertilization with sulphate of ammonia may eventually cause a soil to become acid, due both to the releasing of the sulphuric ion and the gradual depletion of the soil in its lime content. Such has been the experience at Rothamsted, but Prof. Harrison has found in British Guiana that the water of a soil which had received sulphate of ammonia dressings for several successive years showed the same alkalinity as the soil water of land which had been fertilized with nitrate of soda for an equal period of time. It is evident that, as with other agricultural practices, no set law can be established with respect to the action of sulphate of ammonia in all soils, although it is extremely probable that in a soil naturally poor in lime the acidic nature of the sulphate of ammonia dressings will eventually display itself.

The proportions and amounts of elements removed in these experiments are not the same as would occur when the soil is supporting a growth of cane. Lyon and Bizzell* have shown that extensive differences obtain in this respect, when analyzing the drainage water from large tanks of soil, in one series of which nothing was planted, while in others maize and oats were growing. They found that three times as much total solids were removed from the unplanted than from the planted soil, whilst the loss of nitrogen in the drainage waters was twelve times greater in the uncropped than the cropped experiments. The differences were accounted for only partially by the amounts of elements removed by the crops.

CONCLUSION.

The general conclusion is that the results of experiments with soil in small containers, as given in Bulletin No. 34 of this Station, are substantiated.

Molasses applied to land which is receiving the usual fertilizer applications as practiced in these Islands will work harm by causing a part of the nitrogen applied as nitrate to revert back to less available or unavailable forms of nitrogen; by checking the nitrification of sulphate of ammonia dressings; and by retarding the ammonification and nitrification of the nitrogen of organic fertilizers.

The harmful effect of molasses dressings is due entirely to the organic constituents of the molasses, the mineral matters having no influence.

Dressing with carbonate of calcium does not correct such adverse action of molasses.

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* Journal of Industrial and Engineering Chemistry, Oct., 1911.

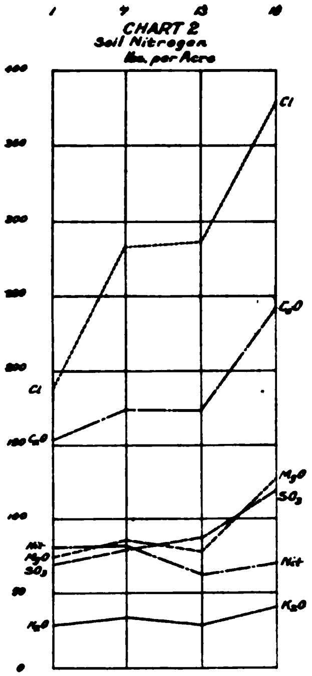
CHART 2
Soil Nitrogen
lbs. per Acre

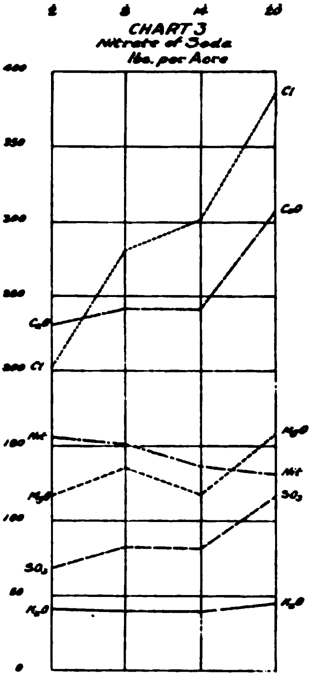
CHART 3
Nitrate of Soda
lbs. per Acre

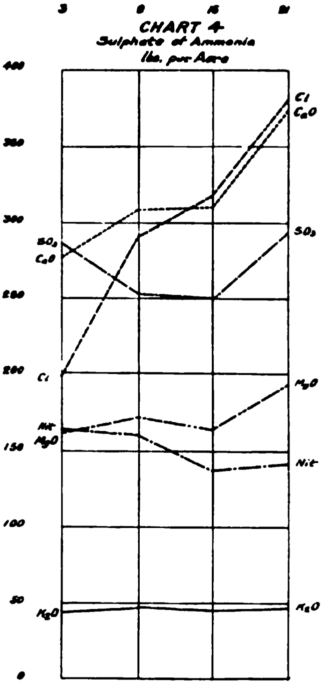
CHART 4
Sulphate of Ammonia
lbs. per Acre

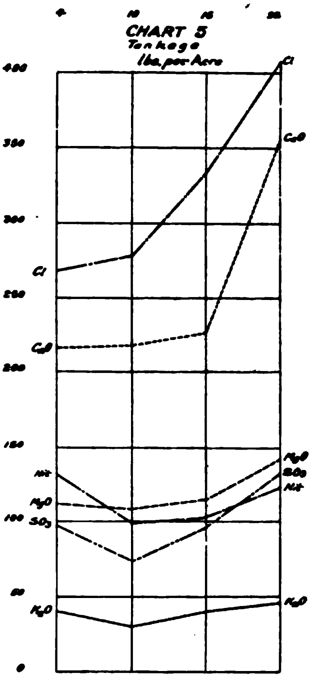
CHART 5
Tankage
lbs. per Acre

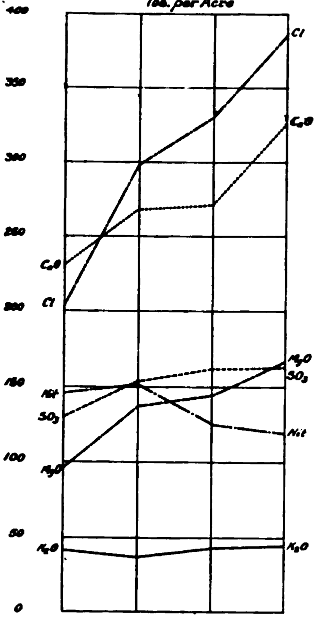

CHART 6
3 Forms of Nitrogen
lbs. per Acre

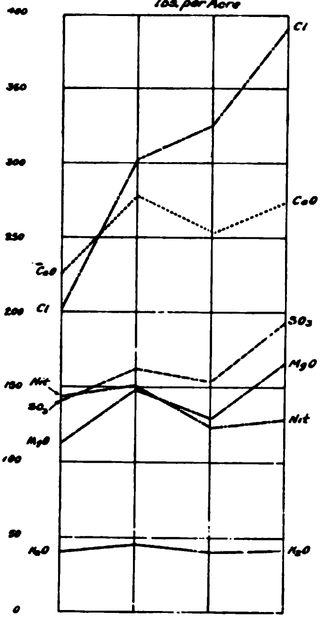

CHART 7
3 Forms of Nitrogen with Calcium Carbonate
lbs. per Acre

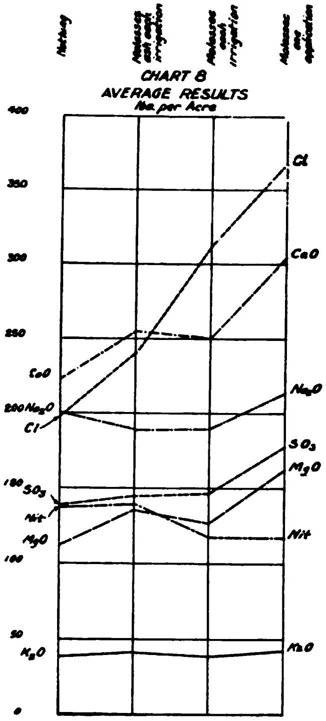

CHART 8
AVERAGE RESULTS
lbs. per Acre

Sci 16

AGRICULTURAL AND CHEMICAL SERIES

BULLETIN No. 40

REPORT OF WORK
OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

Heat of Combustion of Bagasse from Hawaiian Cane.

By R. S. NORRIS

HONOLULU, HAWAII
1912

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JUL 29 19 2

LETTER OF TRANSMITTAL

To the Experiment Station Committee of the Hawaiian
Sugar Planters' Association,
Honolulu, Hawaii.

Dear Sirs:

I herewith submit for publication as Bulletin No. 40 of the Agricultural and Chemical Series, an article by Dr. R. S. Norris, Technical Chemist, entitled: "Heat of Combustion of Bagasse from Hawaiian Cane."

Yours very truly,

C. F. ECKART,
Director.

Honolulu, February 26, 1912.

Heat of Combustion of Bagasse from Hawaiian Cane.

BY R. S. NORRIS

The question often occurs to cane sugar manufacturers why one factory uses a proportionately larger quantity of bagasse for fuel than another. Is it due to a difference in bagasses, or in boilers (including furnaces) or in the handling of the steam? One of the objects of the present investigation has been to attempt to answer for Hawaii that part of the question which has to do with the composition of the bagasse. This question has been investigated to some extent in other cane sugar countries, and always answered in the negative, i. e. but little variation has been found in the amount of heat given off in burning samples of equal amounts of bagasse from different factories. Up to the present time it has been almost the universal rule that there has been sufficient bagasse for the fuel requirements of the factories. But with the tendency toward a demand for constantly increasing extraction of sugar from the cane, and the possibility of the introduction of new varieties with larger percentages of sugar but less fiber, there will come the necessity for a closer study of fuel economy. In this case all the data that it is possible to obtain about bagasse as a fuel will be required.

There are occasional suggestions for the use of bagasse for other purposes than as fuel for running the factories—for the manufacture of paper, for instance. An important consideration in all such questions is the value of bagasse as a fuel compared with other forms of fuel. And in order to determine this it is necessary to know its thermal value or heat of combustion.

There is considerable confusion in the terms used in articles written on the subject of fuels; for instance the subject of this paper can be found referred to under eight different names. It will be well, therefore, to define the terms here used. By

Thermal Value is meant the amount of heat that a unit weight of bagasse furnishes when burned in oxygen. The unit for the measurement of the heat is the *Calorie,* the amount of heat required to raise the temperature of one kilogram of water one degree centigrade. Another unit is also sometimes used—the *British Thermal Unit* (B. T. U.)—which is the amount of heat necessary to raise one pound of water one degree Fahrenheit. The former unit is more generally used in the discussion of thermal values, the latter in boiler tests. The factor for passing from one unit to the other is 1.8. *Fuel value* as herein used means available heat when burned in a boiler furnace under the best conditions. It depends primarily on the thermal value, but also on the amount of moisture in the fuel, the amount of air required for burning and the temperature of the flue gases. One fuel may be best compared with another on the basis of their fuel values.

Another important phase of the question of fuels aside from their thermal value or fuel value, which it is not the purpose of this paper to discuss, is that which has to do with furnace design and construction and style of boilers. It is possible for one lot of bagasse to have the same "thermal value" or "fuel value" as another but show quite different "steaming qualities" when burned in the same furnace, because one requires a different draft or grate surface for proper burning than the other.

PREVIOUS WORK.

The earliest reference to the thermal value of bagasse which the writer has found in the literature of sugar is an article by Robt. Angus Smith[1] in 1869, wherein he quotes from Count D'Adhemar that the "heating power is computed at 4,359 units," and gives the chemical composition of dry bagasse as

Carbon	46.4
Hydrogen	6.07
Oxygen	45.2
Ash	2.32

The bagasse which he analyzed was "the product of a large and powerful mill in the West Indies." From this analysis Alfred Fryer,[2] a few years later, calculated the thermal value of dry bagasse to be 6100 B. T. U.

In a table published in 1884, J. Owen Alexander[3] calculated, from the sugar and fiber content of samples of fresh bagasse in Demerara, the percent of carbon to be 20.73 to 28.54 and the thermal value 2675 to 3683 B. T. U.

Following this there are frequent articles on bagasse to the present day in which the thermal value of bagasse is also calculated either from its elementary constituents,—carbon, hydrogen and oxygen, or from the proportions of the chemical compounds,—sugars, cellulose, etc., of which it is made up. Calculating the thermal value in this way is but guess work, however, and at best can give only approximate results. The only way to determine accurately what the thermal value of bagasse or other fuel may be is by means of a calorimeter—an instrument in which the bagasse is burned and the heat given off measured.

The direct determination of the thermal value of bagasse or cane fiber, as far as the writer knows, was first made at about the same time (1896) by Magruder[4] of the Ohio State University and Atwater[5] of Wesleyan College, Connecticut, the former in connection with some boiler tests with bagasse in conjunction with Pharr, and the latter at the instance of Professor R. T. Burwell of Louisiana. Both tests were on Louisiana cane products. Magruder found as an average of three tests on a sample of bagasse with a Mahler bomb calorimeter, a thermal value of 4520 cal. (8136 B. T. U.) Atwater's test were with a modified Berthelot bomb calorimeter with the following results:

Cane	Heat units per unit weight of dry matter Cal.	 B. T. U.
1. Purple cane, exhaust chips direct from diffusion battery	4622	8320
2. Striped cane, ditto	4605	8289
3. Purple cane, exhaust chips passed through laboratory mill	4616	8309
4. Striped cane, ditto	4658	8384
Average	4625	8325

These latter tests may be considered as having been made on cane fiber, since if there was any sugar in the samples originally it must all have been fermented by the time the tests were made, as they stood for several days with 70 to 90 per cent of water in them.

In 1904, at the request of Geerligs[6], Hoogewerff of Delft and Koning and Bienfait of Amsterdam determined the thermal value of two samples of cane fiber and one of dry cane leaves, with the following results:

Sample	Thermal Value Hoogewerff		Koning & Bienfait	
	Cal.	B. T. U.	Cal.	B. T. U.
Cane leaves	4356	7841	4115	7407
Fiber No. 1	4818	8672	4700	8460
Fiber No. 2	4641	8354	4660	8388

Two years later Koning and Bienfait again tested some samples of fiber for Geerligs,[7] with the following results:*

Cane	Thermal Value of Dry Fiber Cal.	B. T. U.
Black Cheribon 1903	4540	8172
Seedling No. 247, 1903	4625	8325
“ “ 36, 1905	4539	8170
“ “ 100, 1905	4442	7996
“ “ 105, 1905	4514	8125
“ “ 139, 1905	4368	7862
Black Cheribon, 1905	4530	8154

Kerr[8] determined the thermal value of the bagasse from a number of different mills in Louisiana and Cuba in 1909. The average for sixteen samples of dry bagasse was 4654 cal. (8375 B. T. U.). This is higher than Magruder found for bagasse from Louisiana cane thirteen years previously, due, probably, to some extent to the increased extraction resulting from the improvement in milling that has taken place during the interval.

Taking these results as a whole there is but little variation in them. It was to be expected, therefore, that the same would hold true for bagasse and fiber from Hawaiian cane. For the purpose of the investigation it was of prime importance that the instrument and method be capable of giving correct results.

THE CALORIMETER.

The standard instrument for determining the thermal value of fuels is the bomb calorimeter, and though there are several other forms of calorimeters the results from them are only made use of when they correspond with those from the bomb calorimeter. The instrument used in this investigation was an Atwater modification of the Berthelot bomb[9]. Its water equivalent was found from the combustion of pure sugar furnished by the Bureau of Standards at Washington for this purpose. The thermal value 3959 cal.* was taken for the sugar. Using the water equivalent found, the thermal values of several other pure compounds were determined as follows:

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* The thermal value referred to in a postscript to this article, as used by Coates in a lecture on bagasse as a fuel, was quite evidently taken from Atwater's determinations mentioned above.

Substance	Thermal Value Correct	Thermal Value Found
Sucrose, Kahlbaum crystal	3959	3960
Benzoic Acid, Bureau of Standards	6320	6338
Naphthalene, Bureau of Standards	9610	9616

The errors were therefore 0.03%, 0.28% and 0.06% respectively, which are not excessive. In the actual determinations a limit of ± 0.6% variation between duplicates was adopted.

THERMAL VALUE OF FIBER FROM DIFFERENT VARIETIES OF CANE.

Although bagasse and not fiber is the fuel of cane sugar factories, the bagasse from one variety of cane cannot be compared satisfactorily with that from another on account of the possible variation in the amount of juice left in it. And if there is any considerable difference in the thermal value of one sample of bagasse from that of another, containing a similar amount of sugar, it must be due to the fiber, since the quantity of constituents other than fiber and sugar is very small. In order, therefore, to determine whether the variation in the amount of steam obtained in the factories when different kinds of cane are being ground is due to difference in the thermal value of the bagasse, fibers from the leading varieties of cane grown at the Station and from standard varieties grown on the plantations were tested. In preparing the samples of fiber the cane was first put through the horse-power mill at the Station, the bagasse chopped very fine, washed with cold water for about sixteen hours and dried in a vacuum oven at 100° C. As the fiber was found to be quite hygroscopic the precaution was taken to make the combustion as soon as possible after drying, usually the next day, the samples being kept sealed in the meantime in Mason fruit jars. From one and a quarter to one and a half grams of the fiber were used for a charge. On account of the liability to variation in such small samples no attempt was made to obtain duplicate results within less than 0.6% of each other and the thermal values given are the averages of duplicates or in some cases triplicates agreeing within this range.

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* Average of Berthelot's and Stohman's determinations.

TABLE I.

Plat or Plantation	Variety	Thermal Value Calories	Average circumference of stalk inches	Fiber per cent Cane
I	H 349	4564	4.64	12.6
A	H 109	4566	4.90	11.0
A	Yel. Cal.	4580	4.86	14.4
F	Yel. Cal.	4594		14.0
A	Rose Bamboo	4510	4.58	9.6
F	Rose Bamboo	4494		11.1
A	H 33	4495	5.35	9.7
F	Yel. Tip	4576	4.06	14.2
F	H 147	4578	5.16	12.3
I	H 156	4598	5.60	11.9
B	H 269	4523	4.63	11.5
F	H 202	4544	4.62	11.4
F	H 146	4587	4.67	11.8
F	H 227	4521	4.32	10.9
I	H 24	4582	4.57	11.5
D	H 197	4555	4.15	11.6
F	H 212	4527	4.32	10.7
A	Lahaina	4599	4.73	9.7
B	"	4555		9.9
D	"	4596		10.0
F	"	4604		11.3
I	"	4636		10.0
F (12 mo)	D 1135	4556	3.62	11.2
F (12 mo)	H 27	4500	4.36	10.0
F (12 mo)	H 25	4543	4.37	8.8
A	H 309	4581	5.14	9.7
I	H 291	4621	4.72	12.4
D	H 69	4533	4.49	8.2
D	H 240	4571	4.51	12.2
I	H 167	4622	4.41	12.7
B	H 199	4515	4.67	13.4
E	H 69	4542	4.96	....
E	H 27	4583	5.28	....
E	H 20	4613	4.27	....
G	H 239	4560	4.18	....
G	H 355	4588	4.24	....
G	H 349	4563	3.83	....
Ewa	Lahaina (burned)	4572	....	10.8
"	" (not burned)	4599	....	10.9
Olaa	Yel.Cal low lands	4591	....	11.8
Olaa	Yel.Cal high lands	4614	....	10.2
Kohala	Yel. Cal	4620	....	....
McBryde	Yel Cal.	4615	....	13.3
McBryde	Lahaina	4629	....	10.6

These results are practically the same as those obtained for the thermal value of cane fiber in other countries as given above and show conclusively that the *variation in the steam when different kinds of cane are being ground is not due to differences in the thermal value of the bagasse.* The maximum thermal value found was 4636 cal. (8344 B. T. U.) and the minimum 4494 cal. (8089 B. T. U.)—a difference of only three per cent.

An inspection of the table brings out two points of especial interest, (1) that the two standard varieties of cane grown in these islands, Lahaina and Caledonia, rank high in thermal value, and (2) that the combination of high percent of fiber and high thermal value in Yellow Caledonia gives it a unique position as a fuel producer. A case in striking contrast to the latter is that of Rose Bamboo.

THERMAL VALUE OF BAGASSE.

It has not been the practice in the discussions on bagasse as a fuel to draw a sharp distinction between the thermal value of bagasse and that of fiber. But as the value of fiber is higher than that of sucrose* it must therefore likewise be higher than that of bagasse, the difference depending mainly on the amount of sugar in the latter. In the samples tested, the fiber was found to have a thermal value from one to four per cent higher than that of the bagasse from which it was derived.

TABLE II.

	Thermal Value		Bagasse			Sugar
Variety of Cane	**Bagasse**	**Fiber**	**% Sugar**	**% Moist.**	**% Fiber**	**% Dry Bagasse**
H 69	4370	4542	....	....	....	....
H 27	4491	4543	6.2	55.2	....	13.8
H 20	4513	4613	3.7	53.6	....	8.0
H 239	4518	4560	2.6	56.4	....	6.0
H 355	4534	4588	4.7	50.4	42.1	9.5
H 349	4516	4563	....	50.4	45.0	...

From these results it would seem fair to say that the dry bagasse from the mills on these islands has a thermal value of about 100 cal. per kilogram less than the cane fiber. The average value for all the samples of Lahaina and Yellow Caledonia fiber from cane grown on the plantations and at the Station is 4600 cal. *The average thermal value of Hawaiian bagasse would therefore be* 4500 *cal. per kilogram or* 8100 *B. T. U. per pound.*

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* See Page 9.

ELEMENTARY CHEMICAL COMPOSITION OF BAGASSE.

As cane fiber partakes somewhat of the nature of both wood and pure cellulose, it would be expected to lie somewhere intermediate between these two in elementary composition as well as in thermal value, and it does this, but resembles wood more than cellulose, as will be seem by comparing tables III and IV.

TABLE III.

Variety of Cane	Material	Percent carbon	Percent hydrogen	Thermal Value
H 27	Bagasse	48.2 47.9 48.3	5.5 5.7 5.7	4491
H 27	Fiber	49.0 48.8	6.0 6.0	4545
Yel. Cal.	Rind fiber	48.7 48.8	5.8 5.9	4608
Yel. Cal.	Pith fiber	47.3 47.1	5.9 6.0	4393

TABLE IV.[10]

Wood	Pct. carbon	Pct. hydrogen	Therm. Val.
Oak	50.16	6.03	4620
Ash	49.18	6.27	4711
Beech	49.06	6.11	4770
Birch	48.88	6.06	4771
Fir	50.36	5.92	5035
Pine	50.31	6.20	5085

Pure cellulose contains 44.4% carbon and 6.2% hydrogen and a thermal value, according to Berthelot, of 4,200 cal.

These analyses of fiber and bagasse are slightly different from those made elsewhere on the same kind of materials. On account of the strong attraction that dry fiber and bagasse have for moisture the precaution was taken to dry them for several hours immediately before analysis, and to weigh out the samples for combustion as rapidly as possible.

The bagasse proved to be lower than the fiber both in carbon and in hydrogen and the rind fiber was found to contain about one and a half per cent more carbon than the pith fiber.

THERMAL VALUE OF RIND AND PITH FIBER.

As the rind was found to contain more carbon than the pith, it would probably also have a higher thermal value. This was found to be the case in each kind of cane compared in this way.

TABLE V.

Variety of cane	Tissue	% Cane	Fiber % cane	Thermal value of Fiber
H 24	Rind	20.7	31.0	4631
	Pith	79.3	9.8	4412
Yel. Cal.	Rind	22.9	33.8	4608
	Pith	77.1	10.1	4393
H 24	Rind	32.5	21.2	4672
	Pith	67.5	6.6	4549

The rind fiber was therefore about 4% higher in thermal value than the pith fiber. This would tend toward giving canes with stalks of small diameter a higher value than those with large stalks, but an examination of Table I shows that this influence is overcome by other variations in the cane. On an average the fiber of canes with large stalks has as high a thermal value as that from small stalks.

THERMAL VALUE OF FIBER FROM NODES AND INTERNODES.

Just as the rind and pith tissue differ structurally, so does that of the nodes and internodes,[11] and we should, therefore, expect a difference in the thermal value of the latter also. There is a difference, but not as great as between the rind and pith fiber.

TABLE VI.

Variety of cane	Tissue	Fiber % cane	Thermal Value of Fiber
Lahaina	Nodes	19.5	4666
	Internodes	11.9	4597
Yellow Cal.	Nodes	20.1	4612
	Internodes	13.4	4540

According to these results the thermal value of the fiber from the nodes is about one and a half per cent higher than that from the internodes, in the two standard varieties of cane in Hawaii.

FUEL VALUE OF BAGASSE.

In the investigation of fuels for practical purposes there is not much advantage in the direct comparison of thermal values. The amount of heat that can be obtained from a fuel is not dependent solely on its thermal value, though it is necessary to know this in order to determine its value as a fuel. The fuel value may be considered the *net* thermal value, or the available heat per unit weight. The amount of heat available depends on the thermal value, the moisture content, and the total heat removed by all the products resulting from the combustion in the furnace.

The effect of the moisture in the bagasse on its fuel value is in the first place to reduce the amount of combustible matter per unit weight. In a pound of bagasse containing 50% moisture, there is only half a pound of fuel, so that instead of there being 8100 B. T. U.* per pound there are only 4050 B. T. U. to start with. According to the mill reports the moisture in bagasse in Hawaii averages about 45%† and there would, therefore, be 4455 B. T. U. per pound of green bagasse. For other percentages of moisture the heat set free would be as follows:

TABLE VII.

Percent Moisture	Heat contained per pound of Bagasse B. T. U.
42	4698
43	4617
44	4536
45	4455
46	4374
47	4293
48	4212
49	4131
50	4050
51	3969

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* In accordance with the usual custom the British Thermal Unit and Fahrenheit scale of temperature will be used in discussing Fuel Value.

† The moisture in the bagasse as it enters the furnace is probably somewhat less than this owing to evaporation after it leaves the mills.

The moisture in the bagasse reduces the amount of available heat in another manner also—it carries away whatever heat is used in bringing it to the stack temperature. According to Thurston[12] this is usually 600° F. or over, but the average in a number of sugar factories in Cuba, investigated by Kerr,[13] was only 434° F., and he believes that for the highest efficiency it should not be over 500° F.[14] Taking 500° F. as an average for the temperature in the stack, and 85° F.* as the temperature of the water in the bagasse, the loss of heat from this source for each pound of average bagasse would be as follows: $0.45\times(212-85)=57$ B. T. U. to raise the water to the boiling point; $0.45\times966=435$ B. T. U. to convert it into steam, 966 being the latent heat of vaporization of water; and $0.45\times(500-212)\times0.48=62$ B. T. U. to raise the temperature of the steam to 500° F., 0.48 being the specific heat of steam. A total of $57+435+62=554$ B. T. U. to be subtracted from the 4455 B. T. U. in a pound of green bagasse.

There is a further loss also in the heat carried away by the products of combustion, and excess of air. From the elementary analysis given previously we may assume a pound of green bagasse to contain $0.55\times0.48=0.264$ pounds of carbon and $0.55\times0.057=0.0314$ pounds of hydrogen, which on combustion would give $0.264\times3.67=0.969$ pounds of carbon dioxide and $0.0314\times9=0.282$ pounds of water vapor, and would require $0.264\times11.59=3.06$ pounds of air. Taking the excess air as 100%, we would then have in addition to the carbon dioxide and water given above, 3.06 pounds of air and $3.06\times0.77=2.35$ pounds of nitrogen leaving the furnace for every pound of bagasse burned. The air would contain also on an average one and a half per cent, or $6.12\times0.015=0.092$ pounds of water vapor. From the following specific heats we can calculate the total heat carried away by these products of combustion:

Carbon dioxide	0.2163
Nitrogen	0.2438
Air, dry	0.2375
Water vapor	0.48

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* There is probably a variation of as much as 15° F. in this temperature in different factories depending on whether hot or cold water is used for maceration, the distance the bagasse is carried to the furnace, and the temperature of the air surrounding it.

Assuming the temperature of the air entering the furnace to be the same as that of the bagasse,* we would have,—

Loss from combined water $0.282 \times \frac{554}{0.45}$ =347 B.T.U.
Loss from water vapor 0.092×0.48×(500—85)= 18 B.T.U.
Loss from carb. diox. 0.969×0.2163×(500—85)= 87 B.T.U.
Loss from nitrogen 2.35 ×0.2438×(500—85)=238 B.T.U.
Loss from excess air 3.06 ×0.2375×(500—85)=302 B.T.U.

Total loss from products of combustion....... 992 B.T.U.

The combined loss of heat from the products of combustion and the moisture in the bagasse would then be 554+992=1546 B. T. U., leaving available for generating steam in a pound of the bagasse which we have taken as typical, 4455—1546=2909 B. T. U. For bagasse containing different amounts of moisture the available heat, by the same method of calculation, would be as follows:

TABLE VIII.

Percent Moisture	Fuel Value per pound of Bagasse, B T. U.
42	3129
43	3057
44	2982
45	2909
46	2835
47	2762
48	2687
49	2614
50	2540
51	2468

On the basis of these values not only different bagasses may be compared with one another, but bagasse with other fuels through corresponding values for the latter.

The amount of heat which these fuel values represent is not actually obtained for the production of steam, because there are other losses, such as radiation, but these are functions of the furnace rather than of the fuel. There is a slight loss through the heat carried away by the ashes, which directly affects the fuel value, but it is so small as to be practically negligible.

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* It is probably somewhat less, as most of the air comes directly from the outside through the grates.

LOSS OF HEAT IN ASHES.

The ash was determined in a number of samples of fiber and bagasse as follows:

TABLE IX.

Sample	Cane	Percent Sugar in dry sample	Percent Ash
Bagasse	H. 235	9.5	2.07
"	H. 239	6.0	1.73
"	H. 27	13.8	1.31
"	H. 20	8.0	1.41
Fiber	H. 355	....	0.94
Rind Fiber	H. 24	....	1.38
Pith Fiber	H. 24	....	1.22
Fiber	Yellow Calledonia Exp't Station	....	1.41
Fiber	Yellow Caledonia Olaa Plantation	....	1.09
Fiber	Lahaina Ewa Plantation	....	1.38
Fiber	Lahaina McBryde Plantation	....	1.37

According to these results there is less than one percent of ash in green bagasse. Assuming the temperature of the ash when removed from the furnace to be 1000° F. and the specific heat to be 0.20,[15] there would be a loss of less than 2 B. T. U. per pound of bagasse,— $0.01 \times 0.20 \times (1000 - 85) = 1.8$ B. T. U., a negligible quantity, especially in view of the fact that a large proportion of this heat is returned to the furnace by the incoming air.

THERMAL VALUE OF SUBSIDIARY FUELS USED IN CANE SUGAR FACTORIES

MOLASSES.

Hoogewerff[16] determined for Geerligs the thermal value of a sample of Javan molasses containing 19.4 percent water and 9.28 percent ash to be 2953 cal. And Atwater[17] determined for Burwell the average thermal value of the dry matter in several samples of Louisiana molasses to be 3864 cal. Two samples of average Hawaiian molasses gave the following thermal values:*

TABLE X.

No.	Water	Sucrose	Glucose	Purity	Ash	ThermVal.Cal.
1	20.8	35.5	12.7	44.9	14.1	2644
2	21.9	37.6	13.4	48.1	8.4	2854

This is somewhat higher than the thermal value of green bagasse.

DRY CANE LEAVES.

Koning and Bienfait and Hoogewerff[16] determined for Geerligs the thermal value of dry cane leaves from Java to be 4115 cal. and 4356 cal. respectively; a sample of dry leaves from a stripping of cane at the Station gave 4322 cal. per kilogram of dry matter. As gathered, the sample contained 13.8% moisture and 7.3% ash. The thermal value of the material as present in the field was therefore higher than that of green bagasse.

CRUDE PETROLEUM.

It was the intention to make determinations of the thermal value of the crude California oil used in a number of the factories on these islands, but we were unable to get a fresh supply of compressed oxygen in time to include the results in this paper. Many determinations have been made on this fuel by others, however, so its average thermal value is pretty well established. Fenn[18] has published a very comprehensive table of these values for every degree of gravity from 10° Be to 45° Be taken "from the results of numerous tests made by various chemists and practical experts." The oil brought down here for fuel varies from 16° Be to 18° Be, the thermal values of which according to the table of Fenn are:

---

* At the 1909 meeting of the Hawaiian Sugar Planters' Association a report was submitted by the Committee on Manufacture of Sugar and Utilization of Waste Products containing a communication from W. E. Desplace of Queensland, Australia, stating the approximate thermal value of some Australian waste molasses to be 3000 B. T. U. or 1667 cal. (The Hawaiian Planters' Record II [1910], p. 52). This is much lower than any of the values given above and is probably a mistake.

Be degrees	Sp. gr.	Weight per bbl. ℔s.	Therm. val. cal.
15	0.9658	339	10377
16	0.9594	336	10412
17	0.9530	334	10444
18	0.9466	332	10477
19	0.9402	330	10512

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AGRICULTURAL AND CHEMICAL SERIES

BULLETIN NO. 41

REPORT OF WORK
OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

On Available Sugar and a System of Control in the Boiling House

BY NOEL DEERR

HONOLULU, HAWAII
APRIL, 1913

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LETTER OF TRANSMITTAL.

To the Experiment Station Committee of the
Hawaiian Sugar Planters' Association,
Honolulu, Hawaii.

Dear Sirs:—I herewith submit for publication as Bulletin No. 41 of the Agricultural and Chemical Series, an article by Mr. Noel Deerr, Sugar Technologist, entitled: "On Available Sugar and a System of Control in the Boiling House."

Yours very truly,
C. F. ECKART,
Director.

Honolulu, Hawaii, April 17, 1913.

On Available Sugar and a System of Control in the Boiling House

During the past 20 years a large number of formulae mostly originating in Java have been proposed for calculating the available sugar in juices. A complete discussion of these formulae, many of which have now only an historical interest, is to be found in Prinsen Geerligs "De fabricatie van Suiker uit Suikerriet op Java." Of all of these the one which has come into most extended use is that due to Winter and suggested by him in 1897 in the form

$$\text{Available Sugar} = \text{Sugar} - .4\ (\text{Brix} - \text{Sugar})$$

which in 1900 was put by Geerligs and Rose into the form

$$\text{Available Sugar} = \left(1.4 - \frac{40}{\text{Purity}}\right)\ \text{Sugar}$$

This formula of Winter was based on a study of the results obtained in a number of well regulated Javan factories and as used Available Sugar may be paraphrased as "Commercial sugar obtainable under good working conditions, allowance being made for such mechanical losses as occur in practice;" for example with 14% sucrose in juice and 16% Brix and apparent purity 87.5, Winter's formula indicates that per 100 juice there should be obtained in raw sugar

$$14 - .4\ (16\text{-}14) = 13.2$$

It is to be noticed that the formula does not express the available sugar in terms of sucrose in raw sugar per 100 sucrose in juice but as weight of raw sugar on weight of juice, and that Brix and Polarization are the factors used in the formula.

Independently of any work done in Java the writer developed a formula for available sugar; his conception of the meaning of the term "available" was and is different from that used by Winter and others in Java and initially has an algebraic rather than an empirical basis; by "Available sugar" he means that amount of sucrose contained in raw sugar of purity *s* which must be removed from a material of purity *j* until a material of purity *m* results; and he expresses the available sugar as sucrose per cent on sucrose in original material. It is to be observe that sucrose lost in press cake and mechanically is re garded as "available," although under conditions of working it is not "obtainable" or "winbaar" (i. e. capable of being won) in the sense that this word has been rendered as "available" in the English written technical sugar literature.

On this basis the writer obtained the following formula for available sugar:[1]

In unit weight of a juice after removal of water let there be a parts of sugar and b parts of non-sugar. Now let c parts of sugar be removed as in the process of manufacture so that the residue (molasses) now is $1 - c$; let $1 - c$ contain d parts of sugar per unit weight. Since the total amount of sugar was a, the equation $a = c + (1 - c)\,d$ results. Whence $\frac{c}{a} = \frac{(a - d)}{a(1 - d)}$

Now $\frac{c}{a}$ is the proportion of sugar that has been removed and for a which is the proportion of sugar in dry material the purity of the juice may be written and for d the purity of the molasses. The expression then becomes

$$\left.\begin{array}{l}\text{Proportion of Sugar}\\ \text{removed or Extraction}\\ \text{of Sugar in Juice}\end{array}\right\} = \frac{\text{purity juice} - \text{purity molasses}}{\text{purity juice }(1 - \text{purity molasses})}$$

$= \frac{j - m}{j\,(1 - m)}$ where j and m are the purities of the juice and molasses.

That is to say when the purity of juice and purity of molasses are known, the corresponding extraction of sugar per 100 sugar in juice can be calculated.

The calculation is an ideal one under conditions that are not reached in practice, assuming as it does that pure sugar and not an impure product containing a portion of the impurities is made; the impurities contained in the commercial sugar if replaced in the molasses would of course tend to lower the actually observed purity of the molasses. The complete formula can be obtained as follows:

---

[1]. *International Sugar Journal.* 1906 p. 243.

From a material containing a sugar and b non-sugar per unit weight, let there be removed c sugar and d non-sugar and let (c+d) contain e sugar per unit weight. The residue (molasses) is 1—c—d and let it contain f sugar per unit weight.

Then $a=(c+d)e+(1-c-d)f$ or $\dfrac{c+d}{a}=\dfrac{a-f}{a(e-f)}$

or proportional Gross weight of *dry* commercial sugar removed $=\dfrac{j-m}{j(s-m)}$

where j and m are as before and s is the purity of the commercial product.

If the weight of *wet* commercial product is required it is expressed by the formula:

$$\frac{j-m}{j(s-m)}\times\frac{100}{\text{Brix of the Sugar}}$$

The only reliable basis of calculation and method of comparison as between factories is however obtained by referring everything to pure sugar and we then have [2]

$$\text{Sucrose}=\frac{(j-m)}{j(s-m)}\times\frac{100}{\text{Brix}}\times\text{Sucrose \% in commercial product}$$

$$=\frac{s(j-m)}{j(s-m)},$$

---

[2] An identical formula in the form $X=100\,\dfrac{F_t(F_q-S_q)}{Z_t(Z_q-S_q)}$ where F_t and Z_t is the dry substance in massecuite and sugar, F_q Z_q and S_q the true purities of massecuite, sugar and molasses, is quoted by Claassen in his work Beet Sugar Manufacture as the Hulla-Suchomel formula; this formula was used before the writer suggested the formula in the form

$$\text{Available sugar}=\frac{s(j-m)}{j(s-m)}$$

As applied to the recovery per cent by weight on a massecuite the formula above can be expressed:

$$\text{Commercial sugar \% on massecuite} = \frac{B_m \quad (j-m)}{B_s \quad (s-m)}$$

where B_m and B_s are the total solids % in the massecuite and commercial sugar.

So for example if with a juice of 90 purity, raw sugar of 98 purity be removed till molasses of 45 purity remain per 100 sucrose originally present there has been removed

$$\frac{98\ (90-45)}{90\ (98-45)} \times 100 = 93.43\%$$

The formula as developed above demanded true sucrose as opposed to polarization and dry substance as opposed to Brix. Now let this relation hold:

Weight of Juice × Brix = Weight of commercial sugar × Brix + Weight of molasses × Brix; or symbolically if there be w dry matter in the juice and w + a dry matter as deduced from degree Brix (or more generally from specific gravity), from which k *sucrose* is removed there remains w—k residue or w + a — k residue as deduced from degree Brix.

Then from formula (1)

$$\% \text{ of sucrose removed} = \frac{\frac{s}{w} - \frac{s-k}{w-k}}{\frac{s}{w}\left[1-\frac{s-k}{w-k}\right]} \times 100$$

where s is the sucrose in w original dry substance, whence

$$\frac{s}{w} = j \text{ and } \frac{s-k}{w-k} = m$$

This expression reduces to $100 \times \frac{k(w-s)}{s(w-s)} = \frac{k}{s} \times 100$ which is a self evident proposition.

Instead of using dry substance let degree Brix be used; then

$$\text{calculated \% of sucrose removed} = \frac{\dfrac{s}{w+a} - \dfrac{s-k}{w-k+a}}{\dfrac{s}{w+a}\left\{1-\dfrac{s-k}{w-k+a}\right\}} \times 100$$

This expression reduces to $\dfrac{k}{s}\left\{\dfrac{w+a-s}{w+a-s}\right\} \times 100 = \dfrac{k}{s} \times 100$ which is also true.

That is to say in calculations based on a rational formula for available sugar the degree Brix may be used in place of dry substance; since the degree Brix is a convenient method of expressing "Solids as deduced from Specific Gravity" the term *"gravity coefficient"* is proposed for the value of

$$\frac{\text{sucrose \%}}{\text{Degree Brix}} \times 100$$

The formula available sucrose $= \dfrac{s(j-m)}{j(s-m)}$ as developed by the writer was limited in its application owing to the fact that nearly always polarization is accepted as the basis of calculation instead of sucrose per cent and that Brix instead of dry substance was equally generally used. The recognition, however, that the rationally derived formula can be used with gravity coefficients in place of purities removes one objection and the most potent one to its application and the following scheme of analyses for the control of the boiling house is offered, when j, s, and m refer to gravity coefficients.

1. The sucrose entering the boiling house shall be taken as that found in the mixed juice the sucrose being determined by double polarization.

2. The value taken for j shall be that found for the syrup (provided no low sugars are melted in juices); the determina-

tion of j which is defined as the gravity coefficient or the ratio $\frac{\text{sucrose \%}}{\text{Brix}}$ shall be made once daily on an average sample diluted to about 15° Brix.

3. The sucrose % of the sugars shall be determined as well as polarization; the ratio between polarization and sucrose % shall be determined weekly in a composite sample of one week's output.

4. The value taken for s shall be that found for the sugars in dilution of about 15° Brix; this analysis shall be made weekly on a composite sample; in this analysis it will be sufficient to determine $\frac{\text{polarization}}{\text{Brix}}$ using the ratios between sucrose and polarization as found in 3 to determine the gravity coefficient.

5. The value taken for m shall be that found for the waste molasses in dilution of about 15° Brix. This analysis shall be performed as convenient on composite samples.

The syrup has been selected to determine the value of j, since it is the finally purified product which goes to the vacuum pans and since in the very great majority of cases there is a distinct rise in the purity between clarified juice and syrup.

The value found for $\frac{s(j-m)}{j(s-m)}$ then gives the greatest amount of sucrose which can be obtained from that in the syrup i. e. that in mixed juice—loss in press cake—mechanical loss in boiling etc. and hence the value of $\frac{s(j-m)}{j(s-m)}$ must with accurate measurements and analysis always be less than the value of $\frac{\text{sucrose in product}}{\text{sucrose in mixed juice}}$ and it may approximate in value to the value of $\frac{\text{Sucrose in product}}{\text{sucrose in mixed juice—press cake loss—entrainment}}$

It is suggested that in a system of control both these values be compared as under.

Sucrose in mixed juice	1,000 tons
Sucrose in sugars	833 tons
Sucrose in press cake	8 tons
Sucrose entrained	5 tons
Gravity coefficient syrup	84
Gravity coefficient sugars	98
Gravity coefficient molasses	40

$$\text{Then } \frac{s(j-m)}{j(s-m)} = .902$$

$$\frac{\text{Sucrose in sugars}}{\text{Sucrose in mixed juice}} = \frac{883}{1000} = .883$$

$$\text{Net boiling house efficiency} = \frac{.883}{.902} = .979$$

$$\frac{\text{Sucrose in sugars}}{\text{Sucrose in syrup}} = \frac{.883}{1000-8-5} = .895$$

$$\text{Gross boiling house efficiency} = \frac{.895}{.902} = .992.$$

It was pointed out to the writer by Mr. H. S. Walker that the polarization could be used throughout in the formula as devised by the writer and would then give the recovery on *polarization,* and it was suggested by him to the writer that as a control this would be sufficient; for example let there be a juice containing sucrose 15% reducing sugar 1% and of polarization = — .5% sucrose, dry substance 17%, purity 88.24.

$$\frac{\text{polarization}}{\text{dry substance}} \times 100 = \frac{15-.5}{17} \times 100 = 85.29.$$

Let 13% sucrose be removed, then calculated on the polarization $\frac{13\times100}{14.5}$=89.65% has been recovered. The $\frac{\text{polarization}}{\text{dry substance}}$

of the molasses will be $\frac{2-.5}{4} = .375$; using these numbers in the $\frac{j-m}{j(1-m)}$ formula there results $\frac{85.29-37.50}{85.29(100-37.50)} \times 100 = 89.65$

That is to say 89.65% of the *polarization* has been recovered in the commercial product; actually however, only $\frac{13}{15} \times 100 =$ 86.66% of the sucrose has been recovered.

At the same time, however, a check is obtained on the weight of the product since there should be obtained per 100 juice

$$\frac{89.65 \times 14.5}{100} = 13.00 \;.$$

a result given equally accurately when using true values:

$$\frac{86.66 \times 15}{100} = 13.00$$

It then follows that the formula of the writer might be capable of being used with degree Brix and polarization to obtain a rational check on the *weight of the commercial product* though not on the percentage recovery of sucrose.

The work of Browne [3], however, has shown that in ripe juices the reducing sugars consist of dextrose and levulose with the former in excess so much so that generally the optical activity of the mixture is very small and may even vanish; in the process of manufacture there is regularly found first a disappearance of reducing sugars and secondly a isomeric change whereby the activity of the reducing sugars in molasses becomes decidedly laevorotatory; under conditions such as these then the value of *polarization* as an accurate basis of control becomes small.

It has been the writers own experience with tropical cane products—an experience borne out by analyses from Java and elsewhere—to regard 40 as typical of the gravity coefficient of waste commercially exhausted molasses.

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[3] Bulletin 91. Louisiana Exp. Station.

For juices of 80—93 purity and for sugars of 98 purity the following table gives values of $\frac{s(j-m)}{j(s-m)}$ for a gravity coefficient in molasses of 40 and it is suggested that these figures be used as a rough guide in boiling house control.

j	$\frac{98(j-40)}{j(98-40)} \times 100$
80	84.5
81	85.5
82	86.5
83	87.5
84	88.5
85	89.4
86	90.4
87	91.3
88	92.2
89	93.0
90	93.9
91	94.7
92	95.5
93	96.3

As a matter of some interest the writer thought it worth while to see how close it was possible to work with an artificial mixture of pure sucrose and waste molasses. To this end a waste molasses of known composition was mixed with a quantity of pure sucrose of at least 99.95 polarization; now evidently after mixture of sucrose and molasses the product may be regarded as a juice from which the exact amount of sucrose added is available under perfect conditions of working. The results actually found were:

Sucrose taken 80.039 grams

Molasses taken 33.015 grames of 87.35 Brix, 29.90 polarization, 34.23 apparent purity, 82.47 dry substance, 37.82 sucrose, 45.86 purity, 43.29 gravity coefficient. This sucrose and molasses were made up to 749.3 grams of "juice" which were found to be of 14.35 dry substance, 14.55 Brix, 12.00 polarization, 12.37 sucrose, 86.28 purity, 82.48 apparent purity, 85.02 gravity coefficient.

Checking up these analyses there is found

$$\frac{749.3 \times 14.35}{100} = 107.53 \text{ grams dry substance in "juice"}$$

$$80.039 + \frac{33.015 \times 82.47}{100} = 107.27 \text{ grams dry substance in sugar}$$

and molasses

$$\frac{749.3 \times 14.55}{100} = 109.02 \text{ grams solids in juice from Brix.}$$

$$80.039 + \frac{33.015 \times 87.35}{100} = 108.88 \text{ grams solids in sugar and}$$

molasses from Brix.

$$\frac{749.3 \times 12.37}{100} = 92.69 \text{ grams sucrose in juice.}$$

$$80.039 + \frac{33.015 \times 37.82}{100} = 92.52 \text{ grams sucrose in sugar and}$$

molasses.

Since pure sucrose was used the control formula becomes

$$\frac{j-m}{j(1-m)}$$

From the dry substance analyses the quantity of available sugar as a percentage is

$$\frac{.8628-.4586}{.8628(1-.4586)} \times 100 = 86.54\%$$

and as in the "juice" the analysis gave 92.69 grams of sugar the quantity available is 80.223 grams where 80.039 was actually taken or 100.23%, that is to say the combined errors in the analyses amount to .23%.

Using gravity coefficients the available sugar will be

$$\frac{.8502—.4329}{.8502(1—.4329)} \times 100 = 86.55\%$$

a result identical with that found from the true purities.

In the control of the boiling house it is easy to see how in many ways a balance of the dry substance and also of the non-sugar will be of value. In cane sugar factories the writer believes that this is seldom or ever attempted and personally he has considered that actual dry substance determinations of all products would be necessary; these determinations besides unsatisfactory to make are often more than the already overloaded technical staff might arrange. Now, however, since for nearly all substances in dilute solution the relation between per cent of solids in solution and specific gravity is a lineal function it follows that a balance sheet equal in value to a dry substance balance can be constructed on specific gravity determinations alone. Consider for the moment that the quantities to be dealt with are only juice, sugar and molasses; let there be 1000 tons juice of 15° Brix which will then contain 150 tons solids as deduced from specific gravity; for this quantity the term *gravity-solids* is proposed. From this juice there are obtained 125 tons of sugar and 28 tons of molasses. The process of obtaining the gravity solids in the sugar and molasses would be as follows. One hundred grams sugar are dissolved in water and made up to 650 grams; the degree brix of this solution is found to be 15.29; hence the gravity solids in the raw sugar are

$$\frac{650 \times 15.29}{100} = 99.11\%$$ and the 125 tons sugar contain

124.25 tons gravity solids. In a similar way the 28 tons molasses are found to contain 87.6% gravity solids and in all 24.63 tons. The gravity solids balance sheet for this hypothetical case would then appear.

Received in juice	150.00 tons	
Recovered in sugars......	124.25 "	
Recovered in molasses	24.63 "	
Total recovery	149.88 "	=99.26%

In applying this very simple control to the sugar factory the following complications occur:

1. In the mixed juice as weighed there is present solid suspended matter which is not recorded by the indications of the hydrometer. The quantity present may amount to as much as .25% and it would be necessary to determine the amount. The amount present will not be liable to large variation and the writer believes that occasional determinations would be sufficient. The correction for the presence of this insoluble matter would be as follows: Tons mixed juice as weighed 1000 tons; insoluble matter .25% ; tons insoluble matter 2.5; degree Brix of settled mixed juice 15.0; gravity solids in settled mixed juice

$$\frac{(1000-2.5)\times 15.0}{100} = 149.6;$$

gravity solids in mixed juice including therein the insoluble matter 149.6 + 2.5=152.1.

2. The press cake cannot be considered as having any degree Brix; to obtain the solids therein water determinations must be made whence will be obtained the actual dry matter in the cake and since the press cake is largely composed of the suspended solids of the juice the error due to the introduction of actual dry matter in the juice will be partly compensated.

3. The addition of lime after weighing the mixed juice can be allowed for.

4. Scale deposited in the evaporators will cause an apparent loss of gravity solids; in some cases this will be appreciable especially as the salts deposited in general give a higher density coefficient in solution than does organic matter as sugar.

A complete gravity solids balance sheet would then appear as under.

Mixed juice as weighed		100,000 tons	
Suspended solids	.19%		
Actual juice		99,981 tons	
Brix of juice	14.42		
Gravity Solids		14,393 tons	
Suspended Solids		190 tons	
Lime		55 tons	
Total gravity solids		14,638 tons	
Press cake		2,000 tons	
Solids in press cake	35%		
Sugar		12,230 tons	
Brix of sugar	99.40		
Molasses		1,910 tons	
Brix of molasses	87.60		
Solids in press cake		700 tons =	4.8%
Solids in sugars		12,156 tons =	83.1%
Solids in molasses		1,695 tons =	11.4%
		14,529 tons =	99.3%
Scale, various deposits, etc.		107 tons	.7%
		14,636 tons =	100.0%

After having obtained a gravity solids balance it is easy to apply the same reasoning to the obtaining of a non-sugar gravity balance, which of course is the difference between the gravity solids and sucrose.

A balance sheet would appear as follows:

Suspended solids	190 tons	
Gravity non-sugars in juice	1,996 tons	
Lime	53 tons	
Total	2,239 tons	
Gravity non-sugars in press cake	660 tons =	29.4%
Gravity non-sugars in sugars	403 tons =	18.0%
Gravity non-sugars in molasses	1,063 tons =	47.5%
	2,126 tons =	94.9%
Scale, various deposits, etc.	113 tons =	5.1%
	2,239 tons =	100.0%

It is the opinion of the writer that balance sheets made out on these lines of the gravity solids and gravity non-sugars will fill a lacuna in the system of control usually followed in cane sugar houses, more especially in regard to the entrainment losses or losses due to actual destruction of sugar. Consider a case where a close balance is obtained with the gravity solids, an undetermined loss of sugar is shown and where the gravity non-sugar shows an increase; the inference which can be drawn is that entrainment losses are small but that destruction of sugar due to overheating and to inversion has taken place; again if the gravity solids balance shows approximately the same loss as is found for the sugar balance a loss in juice in entrainment in the evaporators is indicated and it is in points such as these that the writer feels that analysis of the results on the previously described basis will be of value. To more fully explain the writer's meaning the balance sheets are given below; these are not from the records of any particular factory but are such as could be duplicated from records in the writer's possession.

A. Satisfactory in all ways.

	Gravity solids	Sucrose	Gravity non-sucrose
Mixed juice	98.2	100.0	89.0
Suspended solids.	1.5		8.5
Lime	.3		2.5
Total	100.0	100.0	100.0
Sugars	83.5	91.0	15.2
Molasses	11.4	9.6	50.3
Press Cake	5.0	.2	34.1
	99.9	99.8	99.6

B. Entrainment in early stages or overweighing of juice indicated.

	Gravity solids	Sucrose	Gravity non-sucrose
Mixed juice	98.2	100.0	89.0
Suspended Solids	1.5		8.5
Lime	.3		2.5
Total	100.0	100.0	100.0

Sugars	80.9	88.5	14.7
Molasses	11.0	9.3	49.5
Press cake	5.0	.2	34.1
	96.9	98.0	98.3

C. Destruction of sugar indicated.

	Gravity solids	Sucrose	Gravity non-sucrose
Mixed juice	98.2	100.0	89.0
Suspended Solids	1.5		8.5
Lime	.3		2.5
Total	100.0	100.0	100.0
Sugars	78.0	87.8	14.5
Molasses	16.4	9.0	56.4
Press cake	5.4	.2	34.1
	99.8	97.8	105.0

Summary.

1. A system of control of the boiling house is suggested based on the formula maximum possible yield $= \frac{s(j-m)}{j(s-m)}$ where s, j, m are the values of $\frac{\text{sucrose \%}}{\text{Brix}}$ of the sugars, the juice and the waste molasses, the ratio being named gravity coefficient to distinguish it from the allied ratios true purity and apparent purity.

2. A further control based on balance sheets of the gravity solids, sucrose and gravity non-sucrose is proposed, by gravity solids being meant the solids as deduced from specific gravity, and the gravity non-sucrose being the difference between the gravity solids and the sucrose.

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AGRICULTURAL AND CHEMICAL SERIES

BULLETIN NO. 42

REPORT OF WORK
OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

An Experimental Study in Multiple Effect Evaporation.

BY NOEL DEERR

HONOLULU, HAWAII
1914

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1914

LETTER OF TRANSMITTAL.

Honolulu, T. H., Feb. 5, 1914.

To the Experiment Station Committee of the
Hawaiian Sugar Planters' Association.

DEAR SIRS:—I herewith submit for publication as Bulletin No. 42 of the Agricultural and Chemical Series, an article by Mr. Nöel Deerr entitled, "An Experimental Study in Multiple Effect Evaporation."

Respectfully,

H. P. AGEE,
Director.

An Experimental Study in Multiple Effect Evaporation.

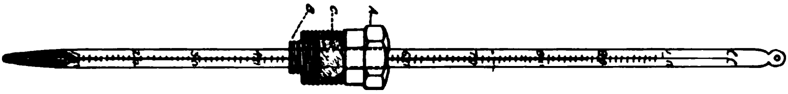
By Noël Deerr.

In this publication is given a record of work done over a period of three years in a number of mills and concerned with multiple effect evaporation under continually reduced pressure.

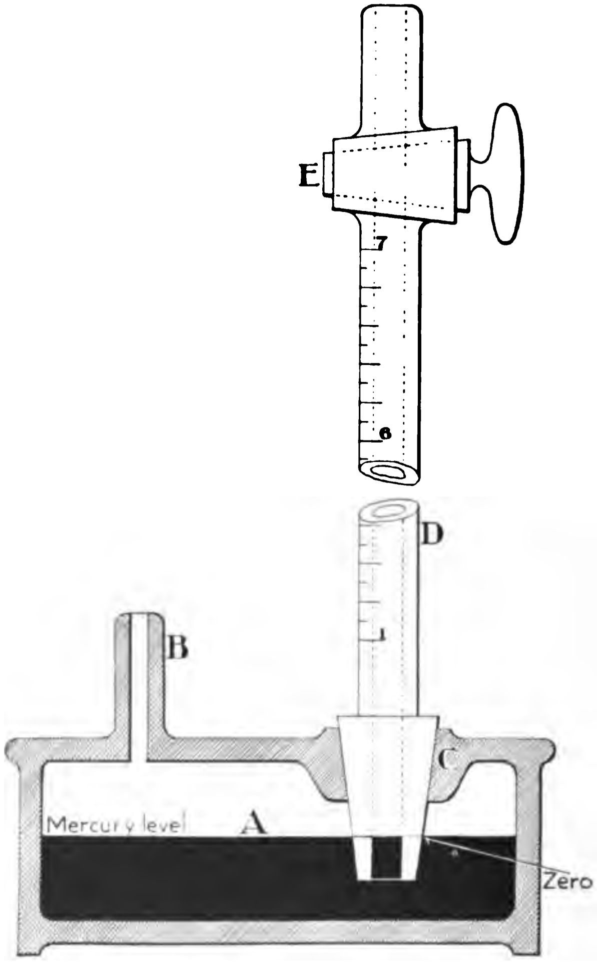
In carrying out this work I am under obligations to the Hawaiian Commercial & Sugar Co., the Ewa Plantation Co., the Paauhau Plantation Co., the Kona Development Co., the Oahu Sugar Co. and the Olaa Sugar Co., in whose factories the experimental work was done. From the technical staff of these factories I received every possible assistance, and I am also indebted to Mr. K. Okamoto for much painstaking observation.

Abbreviations. In the following account of experimental work, C_1, C_2, C_3, C_4, etc., denote the temperature in F° of the steam or vapor entering a cell of an evaporator, VS_1, etc., denotes the temperature in the vapor space; P_1, etc., denotes the pressures which in deference to usage are expressed as inches of vacuum referred to a standard atmosphere of 29.9 inches; J_0, J_1, denote the temperature of the juice entering in cell I, etc., and also is used to denote the Brix of the juices in the cells. CW_1, CW_2, etc., denote the temperature of the condensed waters.

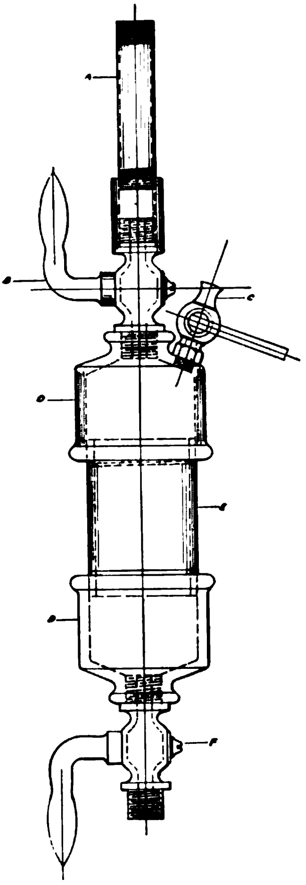
Methods of Observation. All temperatures were read with the type of thermometer generally used in laboratories; those used in these tests were graduated up to 120° C. and could be read to 1/10° C. Holders as shown in Fig. 1 were constructed for these thermometers; the packing used was lamp wick, C, as used in spirit lamps; the inner piece, B, Fig. 1, could be screwed so tight that the difference of pressure did not force the thermometer out, and yet allowed sufficient freedom of movement to move the thermometer up or down as required. Holes were tapped in the vapor pipe or shell of the apparatus corresponding to the outer piece A, Fig. 1; after a trial was finished these holes were closed by corresponding plugs. In making trials the temperature necessary to be observed were read as often as an observer could pass from instrument to instrument.



METHOD OF OBSERVING PRESSURES. The only pressure regularly observed was that in the last cell; actually pressures in the study of a multiple effect evaporator are incidental since it is temperature that is the deciding factor; since, however, the vacuum in the last body forms such a well established and convenient reference point this was observed in all experiments in nearly all cases with a mercury gauge of the form shown in Fig. 2.



A is a shallow receptacle of thick glass partly filled with mercury; on the upper side at B is a tubulure to be connected to the vapor space of the pan by stout rubber tubing; at C is the



neck of the receptacle into which fits tightly the barometer tubing D graduated in tenths of an inch; the receptacle A being filled with mercury, the graduated barometer tubing is then inserted in the neck of the flask and mercury is sucked up above the level of the stop cock at E, which is then closed; the mercury in A is then adjusted until its level is coincident with the zero mark on D; if then connection be made to the vapor space of a vacuum apparatus by way of B, the height of the column of mercury will directly measure the pressure in the pan.

Sampling of Juices. In some experiments it was desired to obtain samples of the juices as they existed in each cell; samples were drawn from the juice pipe lines on this passage from cell to cell; where a pressure existed a pet-cock tapped into the pipe line is all that is necessary to allow a sample being drawn; where the juice was under a vacuum the apparatus shown in Fig 3, constructed out of stock standard fittings, was used.

Method of Altering Vacuum in Last Cell. A large number of tests were made to determine the connection between vacuum in last cell and rate of evaporation, other conditions remaining unchanged. At first the degree of vacuum was controlled by shutting off injection water and lowering the speed of the pump. A much more convenient way was used in later experiments and was simply opening a cock or cocks to the atmosphere and not changing the speed of the pump; after an air cock had been opened to a certain extent it was found that a position of equilibrium very soon obtained and that the vacuum became steady; an operator stationed at the air cock and watching a mercury gauge could easily keep the vacuum constant to within 1/10 inch of mercury.*

Determination of Quality of Steam. The steam admitted to the first cell being of very low pressure the determination if its quality was attended with considerable difficulty. The apparatus available, throtting and separating calorimeters were only adapted for steam of high pressures and apparatus for a direct calorimetric assay of the steam was absent. The quality of the steam was obtained, however, with a reasonable degree of accuracy by an adaption of Carpenter's separating calorimeter. In this apparatus steam from the main is passed through an orifice, the quantity passing being dependent on the pressure of the steam; a very efficient separator collects the entrained water; from observation of the pressure of the steam and measurement of the separated water the percentage of water in the steam can be obtained. Owing to the low pressure of the steam used in evaporation calculation of the quantity passing through the orifice in an arbitrarily selected unit of time is uncertain. The determination was therefore made as follows: the dry steam issuing from the apparatus was condensed by direct injection in a quantity of water contained in a bucket; about two liters of water were used and the condensation of the steam was continued until a temperature of about 180° F. was reached. The quantity of steam condensed was obtained by weighing as was also the quantity of entrained water separated and collected in the instrument. Results of no inconsiderable accuracy were rapidly and conveniently obtained in this way.

Methods Adopted for Determining Rate of Evaporation. The rate of evaporation can be, and was actually, determined in four ways:

a. Measurement of the juice admitted to the apparatus over a definite time interval combined with observations of the density of the incoming juice and outgoing syrup; for definite results the temperature of the incoming juice must also be observed and the quantity of juice in transit in the apparatus must also be the same at the end and beginning of a trial; in all comparative tests this was done by observing the juice levels at the start and by maintaining the density of the discharge constant; the longer the trial the smaller will be the error introduced. This method is the most inconvenient one and was only exceptionally used.

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* In a quadruple apparatus of 14,000 sq. ft. heating surface with dry air slide valve pump 31½" 31½", running at 45 r. p. m. it was found necessary to open an area equal 4.6 sq. ins. to the atmosphere to reduce the vacuum from 27 inches to 23.5 inches. This area must be many times larger than would be found due to leaks in an apparatus of the most careless mechanical construction. Academic calculations of the requisite size of pumps always make an allowance covering more than half the estimated capacity for air leaks, which in view of this experience seems unfounded. This experience also points to a general excessive over size in pumps as usually installed.

b. Measurement of the syrup discharged from the apparatus over a definite time interval combined with the same observations and precautions as in *a* above. In making these measurements two tanks 4 ft. x 4 ft. x 4 ft. were employed alternately filling and emptying; in some trials these tanks were connected by an overflow so that each was always filled to the same level; in other tests the actual depth of liquid in each tank was measured at each filling; at each filling the depth of the undischarged syrup was measured giving, so to speak, the *"tare";* the tanks were provided with four-inch discharge valves, allowing a rapid emptying; tanks of the size are large enough to measure accurately the syrup from 100 tons of cane per hour.

c. The steam condensed in any cell may also be used as a measure of the rate of evaporation provided certain preliminaries are satisfied, since the steam evolved from one cell passes on in series to the next. As regards the steam condensed on the calandria of the first cell some portion of this will generally be used in heating the juice entering that cell, but that portion which represents water evaporated from the juice will, with certain limitations, be reproduced from cell to cell and this portion is capable of easy calculation. If, however, the juice enters the first cell at or near to the temperature at which ebullition is occurring in that cell all the heat represented by the condensation of the steam will appear as steam evolved in that cell. It would, however, be ill advised and open to error to directly use the quantity of water condensed in any cell to calculate the evaporation of an apparatus, although approximate results might be obtained. The relation between water condensed in first cell and evaporation in the apparatus varies, firstly with the heat efficiency of the apparatus including therein radiation losses and steam carried off in the incondensible gas pipes.

In one and the same apparatus, however, worked under uniform conditions except for change in the temperature of heating steam or in the vacuum in the last body the amount of water condensed in and evaporated from the first cell will be a measure of the evaporation in the evaporation in the apparatus as a whole. This prima facie consideration was put to experimental proof and found correct. The measurement of the water discharged from the first cell is an easier observation than the determination of either juice admitted or of syrup discharged; it was, therefore, used in many comparative tests of one and the same apparatus.

d. If the rate of condensation of steam is proportional to the temperature difference between the steam and the surface on which it condenses, then the temperature difference in any cell will be proportional to the rate of evaporation. The conditions in a multiple evaporator are very complex; the passage of heat through the walls of the calandria from steam to juice is controlled by the resistance of the steam, of the boiling juice and of the partition separating them; in the case of thick juices it is known that small differences in their temperature have great effect on their viscosity and consequently on their resistance to the passage of heat. In the first cell, however, the temperature difference between heating steam and boiling juice is small; suppose in a certain case steam in the calandria is at 105° C. and the juice is at 100° C.; the temperature difference is 5° C.; if the temperature of the steam be raised to 106° C. the juice remains at 100° C. the rate of condensation of the steam may reasonably be taken as being increased in the ratio 5:6; if on experiment the quantity of steam condensed in the first cell of a multiple evaporator should be found to be proportional to the temperature difference in that cell then in one and the same apparatus a measure of the rate of evaporation can be found by merely observing the difference in temperature between steam and juice. This argument was put to experimental test and was found to be technically exact. It then follows that alterations in the way of working an apparatus may be tested by the simultaneous observation of the thermometers giving the temperature of the heating steam and of the juice boiling in the first cell.

This observation evidently will not give a measurement of the rate of evaporation as between two separate apparatuses since that will be determined by the efficiency of the apparatus as a whole affected by cleanliness of heating surface, circulation and a multitude of other causes; nor will it give comparative results in one and the same apparatus unless the first cell remains in the same condition; if at one observation the cell is clean and after working for many hours it has become foul the conditions are so altered that one temperature difference has no correlation with the second, but for observations made consecutively the method was found very useful.

Instead of taking the temperature of the juice in the first cell of the apparatus tested it was more convenient to take the temperature of the steam entering the calandria of the second cell; this temperature is, of course, controlled entirely by the temperature at which the juices boil; symbolically then the temperature difference in the first cell was determined as C_1—C_2 and not as C_1—J_1, and actually when temperature observations throughout the series of cells were taken the observations were confined to C_1, C_2, C_3, etc. This abbreviated series of observations sufficient for technical work was necessary owing to the limited numbers of observers available The following record of part of a test of a certain apparatus will show the degree of accuracy, of which these observations are capable.

Keeping the vacuum in the last cell approximately constant the temperature of the heating steam was raised in a series of steps.

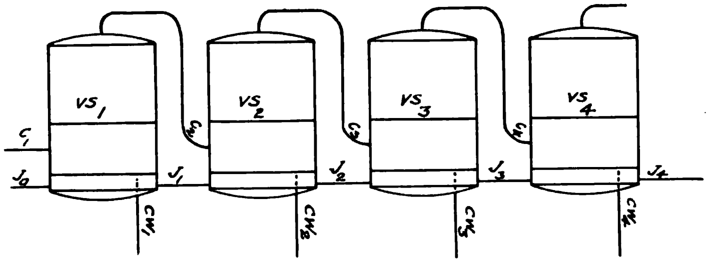
The control of the temperature was effected by manual regulation of the steam valve, the attendant charged with this opening and closing the valve following the fluctuations of a thermometer inserted in the calandria; directions were given him to attempt to maintain the temperature at a fixed point; with practice it was found that a very small variation could be maintained. After the temperature of the heating steam had been changed and obtained constant, ten minutes was allowed to elapse before observations were made. The observations consisted of reading the thermometers C_1 and C_2 every 30 seconds and observing the time required to fill a tank with the discharge from the first cell, so that if the quantity of water discharged and the rate of evaporation be proportional to the temperature difference in the first cell $T(C_1—C_2) =$ constant. Amongst others the following results were obtained:

TABLE I.

C_1	C_2	$C_1—C_2$	T	$T(C_1—C_2)$
212.6	207.1	5.5	1012	5566
216.2	208.9	7.3	776	5655
220.1	211.1	9.0	642	5778
223.3	212.7	10.6	520	5512
226.9	215.6	11.3	479	5313
230.8	218.6	12.2	445	5429

Correlated with this experiment it was seen how evenly an apparatus could be run; the time in seconds for nine successive tanks to fill was found to be: 430, 433, 430, 430, 428, 425, 420, 425, 430.

CONDITIONS PREVAILING IN A MULTIPLE EFFECT. In Fig. 4 is shown a diagramatic sketch of a quadruple effect, lettered to correspond with the nomenclature followed in this publication.



The total fall in temperature or total temperature difference in a multiple effect is defined as $C_1—J_4$ and the temperature difference in any effect as $C_n—J_n$. The available fall in temperature is defined as $C_1—J_1+C_2—J_2+$ etc., and the sum of these terms will approach but never equal the value $C_1—J_4$. In the experiments conducted by the writer when the values of J were determined this was done by reading thermometers inserted in the juice lines; it was generally only at great personal inconvenience that this could be done, and for technical observations $C_1—C_2$, etc., have been taken as the value of the fall in temperature. Consider an apparatus with equally divided heating surface and evaporating a material which does not change in the process of evaporation; it is probable that the values of $C_1—C_2$, $C_2—C_3$, etc., would then be the same unless the passage of heat is affected by the absolute temperature as well as by the temperature difference. In a multiple effect evaporator concentrating sugar juices it is known that $C_4—J_4$ is much larger than any other temperature difference and it is also generally assumed that $C_1—J_1<C_2—J_2<C_3—J_3<C_4—J_4$. In an evaporator with the heating surfaces in all cells in the same condition it is probable that this would be so, but supposing that the heating surface in cell 1 was very foul, then $C_1—J_1$ might well be greater than $C_2—J_2$ and in any other combination irregularities may be observed. It is also to be noted that the prevailing temperatures may be altered at will by regulation of the incondensible gas pipe and so to say, short circuiting steam from one cell to the next in series. In Table II below is given a collection of observations of C_1, C_2, etc., in five apparatuses; these observations were made under normal working conditions. It may be noted that in two apparatuses the temperature difference increases from cell to cell ;in three the variation is irregular, and in two apparatuses there is a larger temperature difference in the first cell than in the second or third; in all, however, the last cell takes up the greatest proportion.

TABLE II.

Variation in Distribution of Temperature in Quadruple Effect Apparatus.

	1 F°	2 F°	3 F°	4 F°	5 F°
C_1	225.5	218.5	230.2	227.7	222.3
C_2	215.8	202.0	213.1	213.0	208.0
C_3	202.7	194.0	201.9	189.0	199.3
C_4	182.9	185.1	184.9	108.1	167.0
VS_4	127.0	143.0	126.0	130.0	122.0
$C_1 - C_2$	9.7	14.0	17.1	14.7	14.3
$C_2 - C_3$	13.1	8.0	11.2	24.0	18.7
$C_3 - C_4$	19.8	8.9	17.0	21.1	31.3
$C_4 - VS_4$	55.9	42.1	58.9	38.0	45.0
$C_1 - VS_4$	98.5	73.0	104.2	97.7	100.3
$\frac{C_1 - C_2}{C_1 - VS_4} \times 100$	9.8	19.2	16.4	14.4	14.2
$\frac{C_2 - C_3}{C_1 - VS_4} \times 100$	13.3	11.0	10.7	23.4	18.6
$\frac{C_3 - C_4}{C_1 - VS_4} \times 100$	20.1	12.2	16.3	20.6	31.2
$\frac{C_4 - VS_4}{C_1 - VS_4} \times 100$	56.8	57.7	56.6	37.1	45.0

TEMPERATURE CONDITIONS IN MULTIPLE EFFECTS WHEN BOILING WATER. Opportunity was taken when a horizontal submerged tube apparatus was being boiled out with water preparatory to a start to take readings at the temperature prevailing in the different cells. The results obtained were:

TABLE III.

	F°	F°
C_1	227.5	219.2
C_2	203.0	203.9
C_3	177.4	179.0
C_4	161.8	161.0
VS_4	134.0	140.0
$C_1 - C_2$	24.5	15.3
$C_2 - C_3$	25.6	26.9
$C_3 - C_4$	15.6	18.0
$C_4 - VS_4$	27.8	21.0

The excessive fall observed with juices between C_3 and C_4 disappears and a more even distribution is found. The irregularities may be caused either by differences in the cleanliness of the different cells or by short circuiting of vapors through the incondensible gas pipe.

EFFECT OF CONCENTRATION IN THE LAST CELL ON THE RATE OF EVAPORATION. As the juice in the last cell gets denser the rate of transmission of heat in the last cell becomes less and consequently more temperature difference is taken up between C_3 and C_4 and less between C_1 and C_2.

An experiment made to determine the effect is given below, which shows a difference of 8% in the rate between a density of 54.8 Brix and one of 64.8 in the syrup in the last cell, as given in Table IV. In this experiment the rate of evaporation was obtained by observing the time, T, taken to fill a tank of 63.5 cu. ft. capacity with the water discharged from cell I; a fair degree of constancy is obtained in the value of T $(C_1—C_2)$.

TABLE IV.

Effect of Concentration in Cell 4 on Rate of Evaporation.

Brix of Syrup	C_1 F°	C_2 F°	VS_4 F°	$C_1—C_2$	$C_1—VS_4$	$\frac{C_1—C_2}{C_1—VS_4} \times 100$	T Secs.	T $(C_1—C_2)$	Rate
54.8	225.5	214.0	124.2	11.5	101.3	11.35	515	5922	1.000
56.3	225.7	214.2	124.2	11.5	101.5	11.32	510	5665	.990
59.0	225.6	214.3	124.6	11.3	101.0	11.19	523	5852	.984
60.6	225.5	214.4	124.4	11.1	101.1	10.97	530	5883	.971
62.0	225.7	214.8	124.8	10.9	100.9	10.82	537	5855	.958
64.8	225.5	214.8	125.0	10.7	100.5	10.65	559	5881	.921

CONNECTION BETWEEN TEMPERATURE AND PRESSURE OF VAPORS. In most articles dealing with multiple evaporation the temperature is taken as that corresponding to the observed pressure. Very early in this series it was observed that especially in the last cell the temperature of the vapors was much higher than corresponded to the pressure. The following observations were made, see Tables V, VI, VII:

TABLE V.

Cell 4, Horizontal Submerged Tube Apparatus.

Vacuum	Temp. F° corresponding to the vacuum	Observed temperature	Superheat F°
23.5	142.8	154.5	11.7
23.9	142.1	153.0	10.9
24.6	135.5	144.0	8.5
24.9	133.3	141.0	7.7
25.8	124.9	137.3	12.4
26.2	121.1	134.9	13.8
26.5	118.0	130.1	12.1

TABLE VI.

Cell 4, Horizontal Film Apparatus.

23.5	142.8	147.5	4.7
24.7	134.8	139.0	4.2
25.0	132.3	137.0	4.7
25.8	124.9	130.0	5.1
26.0	123.1	127.5	4.4

TABLE VII.

Cell 4, Vertical Submerged Tube Apparatus.

24.3	137.7	148.4	10.7
24.9	133.3	145.1	11.8
25.7	125.8	140.4	14.6
26.4	119.0	135.0	16.0
26.9	113.5	130.0	16.5
27.4	105.0	126.0	21.0
27.6	103.0	122.5	19.5

After having observed the very considerable degree of superheat in the last cell observations were made of the correspondence between pressure and temperature in the earlier cells; the observations were made actually with reference to C_2, C_3 and C_4, in the vapor line immediately before the vapor enters an effect; the results are as follows and were obtained by making simultaneous readings of thermometer and mercury pressure gauges. These observations were made only in a vertical submerged tube apparatus.

TABLE VIII.

Calandria 2.

Vacuum Ins. of mercury	Temperature corresponding to the vacuum F°	Actual temperature F°	Superheat F°
6.4	199.2	200.2	1.0
6.7	198.7	199.8	1.1
6.8	198.5	199.8	1.3
6.9	198.3	199.3	1.0
7.1	197.9	199.0	1.1
7.2	197.6	198.8	1.2
7.3	199.4	198.8	1.4

TABLE IX.

Calandria 3.

Vacuum Ins. of mercury	Temperature corresponding to the vacuum F°	Actual temperature F°	Superheat F°
15.8	175.7	178.1	2.4
16.1	174.8	177.3	2.5
16.2	174.5	176.8	2.3
16.4	173.9	175.7	1.8
17.4	170.4	172.7	2.3

This superheating of vapor does not appear remarkable when it is remembered that in the last cell for example juice as much as 50° F. above the temperature at which ebullition occurs under the prevailing pressure in the last cell, enters from the penultimate cell. Vapor is evidently instantaneously formed at the temperature at which the juice enters and the excess of heat does not appear as heat used in evaporation of water, but appears as superheat in the generated vapors.

THE AMOUNT OF WATER EVAPORATED IN EACH CELL. As hotter juice from an earlier cell flows into a later one a certain amount of evaporation independent of the effect produced by the steam is supposed to take place. The amount of this self-evaporation has been calculated in great detail by Hausbrand, who as the result of his calculation finds that in a quadruple effect the total evolution of steam is

Cell I	Cell II	Cell III	Cell IV
1	1.123	1.187	1.316

He has also calculated the concentration in each cell on the basis of which the following figures are an example:

Initial strength %	Cell 1	Cell 2	Cell 3	Cell 4
12.00	14.62	19.10	28.78	65.00

As these calculations have a distinct bearing on design it was considered of interest to determine experimentally the concentration in each cell. Accordingly juice samples were placed on the pipe lines of the effects and over a period of several hours many samples were collected of the juice in transit from cell to cell. The samples were eventually analysed and a selection of the results is given in Table X.

The results are irregular but there is no evidence whatever of a progressive increase in evaporation from cell to cell, but rather on an average each cell evaporates the same quantity of water.

The result was very surprising at first and actually the experiments were initiated as it was hoped thus to obtain a measure of the heat efficiency of the apparatus, as it was thought that any declension from calculation would be a measure of the heat loss.

The non-appearance of the evaporation due to self-evaporation is, however, to be attributed to the superheating of the vapors discussed in the preceding section and will, of course, also be controlled by the heat losses in the apparatus. Another source of irregularity will be found in steam losses occurring through the incondensible gas pipes.

These experiments were made on one horiontal submerged tube and two vertical submerged tube apparatuses.

TABLE X.

Evaporation in Each Cell.

Degree Brix in Each Cell.

J_0	11.07	12.20	11.89	10.91	10.99	12.66	12.13	15.85	15.22
J_1	13.50	15.47	15.59	13.65	13.28	16.07	15.17	19.07	18.39
J_2	18.49	20.61	24.97	18.20	18.28	21.93	19.37	24.15	23.54
J_3	28.52	31.69	31.69	28.21	28.12	31.88	31.64	34.25	34.15
J_4	61.44	63.08	63.54	65.28	60.12	68.80	66.41	60.62	64.32

% Evaporation in Each Cell.

1	18.00	21.14	23.74	20.07	17.24	21.14	20.07	16.87	17.26
2	21.87	19.66	19.05	19.97	22.65	19.66	17.30	17.50	18.10
3	21.05	19.49	19.69	21.28	20.02	19.49	16.92	19.35	20.07
4	20.80	20.37	20.38	21.96	20.80	20.87	17.44	21.13	19.75

Loss of Temperature Between Cells. Only two series of observations were made on this point, one series was made on a horizontal submerged tube apparatus of 11,284 sq. ft. heating surface; the apparatus exposed an area of 2,950 sq. ft. of which 1,670 sq. ft. were lagged with 1 inch asbestos and 1,250 sq. ft. were bare. The vapor pipes were: 1-2, 17 inches; 2-3, 20 inches; 3-4, 24 inches in diameter. The temperature loss was found to be

VS_1 to C_2	1.9° F.
VS_2 to C_3	2.3° F.
VS_3 to C_4	4.0° F.
Total	7.2° F.

The total temperature fall being about 100° F., a loss of temperature difference of 7% or thereabouts is indicated. The second apparatus was a vertical submerged tube apparatus of 14,146 sq. ft. heating surface with an exposed area of 2,750 sq. ft., all of which except 290 sq. ft. constituting the bottoms of the cells was lagged with 2-inch asbestos and ½-inch wood. The vapor pipes were: 1-2, 23 inches; 2-3, 27 inches; 3-4, 31 inches in diameter. The temperature loss was found to be

VS_1 to C_2	.2° F.
VS_2 to C_3	.7° F.
VS_3 to C_4	.8° F.
Total	1.7° F.

Temperature of the Condensed Water. It was found on experiment that the temperature of the condensed water in each cell left just a fraction of a degree below the temperature of the steam or vapor entering the cell and not at the temperature of the juice in the cell; that is to say C_n nearly equals CW_n and CW_n is not $= J_n$. There is then very little transfer of heat from the condensed water to the boiling juice. Some actual observations follow:

TABLE XI.

	F°	F°	F°	F°	F°
C_1	220.8	222.8	230.0	219.4	221.4
CW_1	220.4	222.0	229.4	219.0	221.0
C_2	210.4	212.0	211.0	210.6	214.0
CW_2	210.0	211.2	210.4	210.0	213.3
C_3	196.4	198.4	197.2	188.4	190.2
CW_3	195.8	198.0	196.7	187.7	189.6
C_4	180.2	178.4	184.3	180.0	179.1
CW_4	180.0	177.6	184.0	179.2	178.5

RATE OF EVAPORATION AS INFLUENCED BY THE VACUUM IN THE LAST CELL. The following statement occurs in Claassen's "Beet Manufacture," p. 122, English Edition:

"The means at hand for increasing the heat-transference of the last effects are to increase the temperature-fall and to keep the boiling-temperature not too low by too high a vacuum. If the vacuum rises much above 60 cm. (24 inches), it is true that the temperature-fall increases more in proportion to every centimeter rise in the vacuum, but the heat-transference coefficient decreases in much greater portion as the boiling-temperature sinks. Hence it appears useless to keep the vacuum higher than 60 cm., and indeed such high vacuums are difficult to reach unless a large amount of cold water and a perfectly working vacuum-pump are available. Taking all circumstances of actual practice into consideration, it is best to work at a vacuum of about 60 cm."

This point is of great interest and many experiments were made to test it, in the first place as a general rule it may be accepted that the rate of evaporation is proportional to the temperature fall, that is to say to $C_1—J_4$, but it should not be accepted that the rate is independent of the conditions under which the value of $C_1—J_4$ is the same; for example, C_1 may be say 230° F. and J_4 may be 130° F., making $C_1—J_4=100°$ F.; if C be reduced to 218° F. and J_4 to 118° F., $C_1—J_4$ again is 100° F., but it does not follow that the rate of evaporation is the same in both cases.

Series 1. Quadruple effect horizontal tube film evaporator. In this series measurements were made of the water condensed in the first cell, of the syrup discharged with determination of the Brix of J_0 and J_4 and of the value of $C_1—C_2$. The experiments in each case were of one hour's duration. The results obtained were, see Table XII.

TABLE XII.

C_1 F°	C_2 F°	$C_1 - C_2$	VS_4 F°	$C_1 - VS_4$	Vacuum Inches	$\frac{C_1 - C_2}{C_1 - VS_4} \times 100$	Rate as proportional to $C_1 - C_2$	Rate as deduced from water condensed in cell 1.	Rate as deduced from syrup discharged.
222.1	208.9	13.2	122.1	100.0	26.7	13.2	1.000	1.000	1.000
222.8	210.2	12.6	131.4	91.4	25.7	13.8	.955	.970	.964
223.3	211.3	12.0	140.0	83.3	24.6	14.4	.909	.896	.884
221.3	210.4	10.9	148.0	73.3	23.5	14.9	.827	.845	.836

In this experiment no very great constancy was obtained in the value of C_1; a second experiment made only so far as regards temperature difference gave the following results. See Table XIII.

TABLE XIII.

C_1 F°	C_2 F°	$C_1 - C_2$	VS_4 F°	$C_1 - VS_4$	Vacuum Inches	$\frac{C_1 - C_2}{C_1 - VS_4} \times 100$	Rate
222.8	209.6	13.2	123.0	99.8	26.3	13.4	1.000
222.9	210.2	12.7	132.0	90.9	25.6	14.0	.962
222.9	211.0	11.9	139.7	83.2	24.6	14.3	.902
223.0	211.5	11.5	147.1	75.9	23.7	15.2	.872

After making these experiments it was found more convenient to compare the normal vacuum used in the factory with one other vacuum rather than attempt to make four determinations in one day. The following results were obtained, see Table XIV.

TABLE XIV.

C_1 F°	C_2 F°	$C_1 - C_2$	VS_4 F°	$C_1 - VS_4$	Vacuum Inches	$\frac{C_1 - C_2}{C_1 - VS_4} \times 100$	Rate as proportional to C_1—C_2	Rate as deduced from water condensed in cell 1.	Rate as deduced from syrup discharged.
231.8	207.1	24.7	122.8	109.0	26.5	22.7	1.000	1.000	1.000
231.8	207.8	24.0	131.9	99.9	25.6	24.1	.971	.977	.979
232.3	205.9	26.4	123.1	109.2	26.2	24.2	1.000	1.000	1.000
232.2	207.9	24.3	140.0	92.2	24.6	26.7	.920	.918	.902
231.6	209.8	21.8	124.0	107.6	26.1	20.2	1.000	1.000	1.000
231.8	212.5	19.3	147.1	83.7	23.7	23.7	.885	.863	.872

These series of experiments give then an increase in the rate of evaporation with increase in vacuum in the last cell between the limits of 23 inches of vacuum and 27 inches of vacuum, the rates of evaporation as found from consideration of the temperature difference the condensed water from cell 1 and the syrup discharged from cell 4 being in fair agreement.

Series II. These experiments were made in a quadruple effect vertical submerged tube apparatus. The method of testing was based on timing the period required to fill a tank of 63.5 cubic feet with the discharge from the first cell. At the same time the following temperature observations were made, C_1, C_2, VS_4 and the vacuum in the last body. The temperature was kept as constant as possible by hand control of the live steam valve. The results are given in tabular form in tables XV and XVI, T denoting the time in seconds required to fill the tank.

TABLE XV.

C_1 F°	C_2 F°	VS_4 F°	$C_1 - C_2$	$C_1 - VS_4$	$\frac{C_1 - C_2}{C_1 - VS_4} \times 100$	Vacuum Inches	T Secs.	T $(C_1 - C_2)$	Rate as proportional to $C_1 - C_2$	Rate as deduced from water discharged from cell 1.
219.3	210.2	123.2	9.2	96.2	9.56	27.0	716	6587	1.000	1.000
219.4	210.6	130.5	8.8	88.9	9.89	26.2	750	6600	.955	.956
219.4	211.1	135.6	8.3	84.8	10.24	25.4	825	6647	.878	.902
219.4	211.5	143.0	7.9	96.0	10.39	24.6	849	6667	.855	.859
219.4	211.8	146.7	7.6	72.7	10.46	24.1	900	6840	.795	.827

TABLE XVI.

220.1	210.7	122.5	9.4	97.6	9.63	27.6	568	5339	1.000	1.000
220.1	211.0	126.0	9.1	94.1	9.66	27.4	599	5491	.948	.967
220.0	211.2	130.0	8.8	90.0	9.78	26.9	640	5632	.897	.936
219.9	211.4	134.9	8.5	85.0	10.00	26.4	692	5882	.823	.905
220.0	211.5	135.0	8.5	85.0	10.00	26.4	701	5958	.810	.905
219.8	211.7	140.4	8.1	79.4	10.24	25.7	754	6112	.753	.862
220.1	212.2	145.1	7.9	75.0	10.53	24.9	772	6098	.735	.840
220.1	212.4	148.4	7.7	71.7	10.82	24.3	835	6432	.678	.819

Series III. This was a duplicate of Series II in a different apparatus of 8996 sq. ft. heating surface. The results are as below in Tables XVII and XVIII; in this series the temperature

J_1 was taken in place of C_2 and C_1—J_1 as the temperature difference in the first cell.

TABLE XVII.

C_1 F°	J_1 F°	VS_4 F°	$C_1 - J_1$	$C_1 - J_4$	$\frac{C_1 - J_1}{C_1 - J_4} \times 100$	Vacuum Inches	T Secs.	T $(C_1 - C_2)$	Rate as proportional to $C_1 - J_1$	Rate as deduced from water condensed in cell 1
224.1	213.1	120.0	11.0	104.1	10.56	26.8	530	5830	1.000	1.000
224.1	213.3	131.0	10.8	93.1	10.80	25.9	540	5832	.981	.982
224.2	214.0	137.4	10.2	86.8	11.20	24.9	603	6150	.878	927
224.2	215.0	146.0	9.2	78.2	11.77	24.0	662	6090	.801	.835

TABLE XVIII.

C_1 F°	J_1 F°	VS_4 F°	$C_1 - J_1$	$C_1 - J_4$	$\frac{C_1 - J_1}{C_1 - J_4} \times 100$	Vacuum Inches	T Secs.	T $(C_1 - C_2)$	Rate as proportional to $C_1 - J_1$	Rate as deduced from water condensed in cell 1
221.0	210.5	116.0	10.5	105.1	10.00	27.4	561	5850	1.000	1.000
220.8	210.5	125.6	10.3	95.2	10.82	26.5	621	6396	.903	.981
220.8	210.8	133.0	10.3	87.8	11.29	25.7	670	6700	.837	.953
220.9	211.3	133.0	9.6	82.9	11.58	25.0	693	6653	.803	.916
221.1	211.8	142.6	9.3	78.5	11.97	24.2	770	7161	.729	.887
221.0	212.0	146.0	9.0	75.0	12.00	23.8	825	7425	.680	.858

Series IV. This experiment was made in a triple effect apparatus of 3000 sq. ft. heating surface and was concerned only with the determination of the value $C_1—C_2$, and of the ratio $\frac{C_1 - C_2}{C_1 - VS_4}$ where C_1 remains constant and VS_4 varies. In a certain mill which worked with an abnormally high exhaust pressure, arrangements were made to remove some of the weights from the valve on the exhaust line so that steam blew off under a constant pressure. In this experiment the temperature in the calandria of cell 1 remained exactly constant throughout the whole time of the experiment. The results are given in Table XIX.

TABLE XIX.

C_1 F°	C_2 F°	VS_4 F°	$C_1 - C_2$	$C_1—VS_4$	Vacuum Inches	$\frac{C_1 - C_2}{C_1 - VS_4} \times 100$	Rate
226.4	216.2	125.0	10.2	101.4	26.0	10.06	1.000
226.4	216.5	129.5	9.9	96.9	25.3	10.22	.970
226.4	216.8	134.4	9.6	92.0	25.0	10.43	.941
226.4	216.9	137.4	9.5	89.0	24.5	10.67	.930
226.4	217.2	141.5	9.2	84.9	24.0	10.83	.902
226.4	217.4	145.8	9.0	80.6	23.2	11.18	.882
226.4	217.6	148.6	8.8	77.8	22.7	11.32	.863

Series V. This series was made on a horizontal tube film evaporator. The value of VS_4 was not taken and the rate was obtained from measurement of the syrup. Results are given in Tables XX and XXI.

TABLE XX.

C_1 F°	C_2 F°	$C_1 - C_2$	Vacuum Inches	Rate as deduced from syrup discharged	Rate as proportional to $C_1 - C_2$
212.6	203.6	9.0	26.4	1.000	1.000
212.7	203.8	8.9	25.8	.989	.989
212 6	204.0	8.6	24.9	.909	.955
212.8	204.7	8.1	24.1	.876	.900

TABLE XXI

212.4	203.0	9.4	27.0	1.000	1.000
212.4	204.1	8.3	25.9	.907	.883
212.4	204.8	7.6	24.9	.806	.808

This whole series of experiments may be thus summarized:

1. In a multiple effect evaporator in which the heating steam is

kept at constant temperature there is a progressive increase in the rate of evaporation as the vacuum in the last cell or the total fall in temperature is increased.

2. The difference in temperature in the first cell is an index of the rate of evaporation of the whole apparatus.

3. There is evidence that the rate of evaporation increases more rapidly than the temperature difference increases; that is to say the product of T (C_1—C_2) tends to increase as T increases.

4. As the vacuum in the last cell is decreased and consequently the total fall in temperature is decreased a greater percentage of the fall is taken up in the first cell, but this increase in the percentage taken up in the first cell is not sufficient to compensate for the decrease in the total fall in temperature.

6. Pump capacity being cheaper than heating surface it will always pay to maintain a high vacuum in the last cell.

RATE OF EVAPORATION AS INFLUENCED BY HIGHER INITIAL TEMPERATURE. This series of experiments, the converse of those described in the preceding section, were performed in two vertical submerged tube apparatuses.

In a preliminary experiment instructions were given to the operator *to gradually increase* the steam pressure or value of C_1; observers stationed at C_1 and C_2 took simultaneous readings of the values of C_1 and C_2 every thirty seconds. The whole experiment was concluded within 15 minutes with the results shown below, in Table XXII.

TABLE XXII.

C_1 F°	C_2 F°	$C_1 - C_2$
221.5	212.0	9.5
221.4	212.0	9.4
223.1	212.2	10.9
223.5	212.4	11.1
225.0	212.3	12.7
225.3	212.4	12.9
226.0	212.2	13.8
226.2	212.0	14.2
226.6	212.4	14.2
226.5	212.6	13.9
227.6	212.6	14.0
228.3	213.3	15.0
229.6	213.8	15.8
230.4	214.7	15.7
231.6	215.4	15.2
231.8	215.8	16.0
230.0	215.4	14.6
228.0	214.7	13.3
226.2	214.7	11.5
223.7	213.0	9.7
220.8	213.9	6.9
220.5	212.0	8.5
219.6	211.7	7.9

The detailed results of the trials are given in Tables XXIII, XXIV and XXV.

TABLE XXIII.

Pressure in cell 1 Lbs. per sq. in.	C_1 F°	C_2 F°	VS_4 F°	$C_1 - C_2$	$C_1 - VS_4$	$\frac{C_1 - C_2}{C_1 - VS_4} \times 100$	Vacuum Inches	T Secs.	T ($C_1 - C_2$)	Rate as deduced from water discharged from cell 1	Rate as proportional to $C_1 - C_2$
.1	212.4	204.8	113.0	7.6	99.4	7.64	27.7	721	5480	1.000	1.000
1.5	217.0	208.3	113.2	8.7	103.8	8.38	27.6	655	5699	1.108	1.142
2.3	219.7	210.5	113.8	9.2	105.9	8.61	27.6	622	5722	1.127	1.210
4.1	224.9	213.9	115.2	11.0	109.7	10.03	27.3	590	6490	1.227	1.449
5.8	229.2	216.4	116.0	12.8	113.2	11.30	27.2	500	6400	1.442	1.682

TABLE XXIV.

.2	212.6	207.1	120.3	5.5	92.3	5.96	27.0	1012	5566	1.000	1.000
1.4	216.2	208.9	121.2	7.3	95.0	7.68	26.9	776	5665	1.306	1.326
2.5	220.1	211.1	122.5	9.0	97.6	9.23	26.7	642	5778	1.576	1.633
3.7	223.3	212.7	123.4	10.6	98.9	10.71	26.6	520	5512	1.949	1.929
4.9	226.9	215.6	124.6	11.3	102.3	11.02	26.5	479	5413	2.114	2.053
6.3	230.8	218.6	126.0	12.2	104.8	11.65	26.3	445	5329	2.275	2.218

TABLE XXV.

.1	212.4	207.5	119.0	4.9	93.4	5.24	27.1	915	4484	1.000	1.000
1.3	216.0	209.7	120.4	6.3	95.6	6.59	26.9	711	4479	1.287	1.287
2.5	220.1	210.8	123.0	8.3	97.1	8.55	26.7	562	4665	1.628	1.696
3.7	223.3	213.6	123.9	9.7	99.4	9.75	26.6	525	5093	1.723	1.982
4.9	226.9	216.8	125.1	10.1	101.8	9.82	26.5	495	4999	1.848	2.040
6.3	230.7	220.3	127.4	10.4	103.3	10.06	26.3	453	4710	2.019	2.120

The results of these experiments may be summarized:

1. As the temperature (or pressure) of the heating steam rises from 212° F. to 230° F. (or from a gauge pressure of 0 to 6.5 lbs. per sq. in.) there is a very rapid rise in the rate of evaporation, which between these limits may double.
2. As the temperature of the heating steam increases the percentage of the total fall taken up in the first cell also increases.
3. The increase in the rate of evaporation is in much greater proportion than is the increase in the total fall in temperature.

General Conspectus of the Effect in Variation of C_1 and VS_4 on the Rate of Evaporation. For the purposes of easy comparison the results of two series made in one and the same apparatus under conditions as close as possible are brought together in Tables XXVI and XXVII.

These experiments include a range for C_1 from 212.6° F. or just over atmospheric pressure to 230.8° F. or a pressure of over 6 lbs. gauge; a range in VS_4 from 120° F. to 148° F. corresponding to gauge readings of 27.5 inches to 24.0 inches of vacuum and to a total temperature difference of from 71.7° F. to 104.8° F. Inspection of these results (column 9) brings out a point of very considerable interest, which may be expressed thus. In a quadruple effect apparatus the percentage of the total fall in temperature taken up in the last cell, that is to say, the value of $\frac{C_4 - VS_4}{C_1 - VS_4}$ is independent of variation in C_1 and VS_4. The total fall in temperature is not at once a measure of the rate of evaporation, which is also controlled by the absolute temperature prevailing in the apparatus and in a very remarkable manner. When C_1 is increased from 212.6 to 230.8, C_1—VS_4 is increased from 92.3 to 104.8, the rate of evaporation increasing in the same time as the ratio 445 to 1012, that is to say a very great increase is to be attributed to the higher temperature prevailing, at the same time the temperature difference in the last cell rises from 48.7 to 58.0, the rate of evaporation increasing in the ratio 445 to 1012; when, however, C_1 is kept constant and a higher temperature prevails in the apparatus due to increasing VS_4 a very much smaller increase due to higher temperature obtains; thus with a total fall of 97.6 F° the tank took 508 seconds to fill and with a total fall of 71.7° F. it took 835 seconds to fill; now $\frac{568}{835} = .735$ and $\frac{71.7}{97.6} = .680$,

TABLE XXVI.

Effect of Varying C_1 With VS_4 Constant on the Rate of Evaporation and Temperature Distribution.

C_1 F°	C_2 F°	C_4	VS_4 F°	$C_1 - C_2$	$C_4 - VS_4$	$C_1 - VS_4$	$\frac{C_1 - C_2}{C_1 - VS_4} \times 100$	$\frac{C_4 - VS_4}{C_1 - VS_4} \times 100$	T Secs.
212.6	207.1	169.0	120.3	5.5	48.7	92.3	5.95	53.1	1012
216.2	208.9	171.7	121.2	7.3	50.5	95.0	7.68	53.1	776
220.1	211.1	175.1	122.5	9.0	52.6	97.6	9.22	53.9	642
223.3	212.7	178.1	123.4	10.0	54.7	98.9	10.71	55.2	520
226.9	215.6	181.2	124.6	11.3	56.6	102.3	11.05	55.1	479
220.8	218.6	184.0	126.0	12.2	58.0	104.8	11.64	55.4	445

TABLE XXVII.

Effect of Varrying VS_4 With C_1 Constant on the Rate of Evaporation and Temperature Distribution.

220.1	210.7	176.2	122.5	9.4	53.7	97.6	9.63	53.0	568
220.1	211.0	177.8	126.0	9.1	51.8	94.1	9.66	55.0	599
220.0	211.2	181.0	130.0	8.8	51.0	90.0	9.78	56.6	640
219.9	211.4	183.1	134.9	8.5	48.2	85.0	10.00	56.6	692
220.0	211.5	183.0	135.0	8.5	48.0	85.0	10.00	56.5	701
219.8	211.7	187.5	140.4	8.1	47.1	79.4	10.24	59.3	754
220.1	212.2	188.0	145.1	7.9	42.9	75.0	10.53	57.2	772
220.1	212.4	189.0	148.4	7.7	40.6	71.7	10.82	56.5	835

a very different rate of increase to be attributed to higher temperature than when C_1 was increased.

In the series with VS_4 varying there is another remarkable point; with $VS_4 = 122.5$ $C_4 - VS_4$ was 53.7; when VS_4 is 148.4 $C_4 - VS_4$ is 40.6; now $\frac{40.6}{53.7} = .755$ and $\frac{568}{835} = .680$, so that although in the second case the fourth cell is hotter the rate of evaporation per degree fall is decreased; this can be explained by introducing another factor and it is probable that in the last cell the rate of transfer of heat increases not as a linear function of the temperature difference but much more rapidly. As another comparison take the second result in the first table and the penultimate one in the second table; the apparatus was working at the same rate in both cases, although it is by no means certain other conditions such as scale were the same. In the one case $C_4 - VS_4$ is 50.5 and in the second the value is 42.9; in the second case the temperature is higher; the varying conditions here have just balanced.

In commencing these experiments the writer had hoped to have obtained data to solve the following problem: "Given a certain area of heating surface how to divide the same so as to obtain the greatest rate of evaporation." The writer has been unable to solve this problem and has to be content with merely indicating it in a simple form. Consider a double effect with equally divided heating surface = a in each body; let the total fall in temperature be 100° of which 20° obtains in the first cell and 80° in the second cell; add another unit to the first cell making the first cell 2a and the total 3a; the same evaporation will now be done in the first cell with a fall in temperature of 10° leaving 90° for the second cell; suppose the transfer of heat in the second cell varies with some power of the temperature difference; let this power be n; then if $\left(\frac{90}{80}\right)^n > 1.5$ evidently the capacity of the apparatus per sq. ft. has been increased. A study of the results tabulated above points to an increase in the rate of evaporation with decreasing heating surface from cell 1 onwards; it is, however, so much to the advantage of constructors to make all the cells from the same patterns that an apparatus with exactly divided surface will remain a standard type. Where as sometimes happens due to amalgamations evaporating plants are made up of different apparatus, it would probably be better to install any larger cell as the first cell; this is all the more so since the first cell has generally to perform heating as well as evaporation. The argument that the greater scale formation in the later cells demands a larger heating surface is not *to be readily accepted* since with formation of scale a still greater temperature difference will be required to keep the juices in the later cells in active ebullition; the presence of scale is actually in line with the low conductivity already found in the last cell.

THE HEAT ECONOMY OF MULTIPLE EFFECT EVAPORATORS. The actual amount of water evaporated per lb. of steam supplied in a multiple effect evaporator will depend absolutely on:

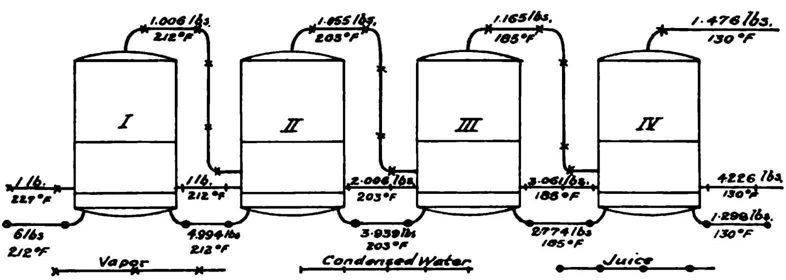
1. The total heat in the steam supplied.
2. The total heat in the juice entering the first cell.
3. The total heat in the discharged syrup.
4. The total heat in the discharged water of condensation.
5. The total heat in the vapor discharged from the last cell.

Under working conditions the evaporation will be affected by:

1. The method of evacuation of the condensed waters.
2. The short circuiting of steam along with the incondensible gases.
3. The degree of superheat in the vapors.
4. Radiation losses.

The maximum evaporation will occur when the condensed waters are passed from cell to cell and leave the calandrias at the temperature at which the juice is boiling in that cell; that is to say when $CW_n = J_n$ and not $= C_n$ as actually occurs.

An academic computation of this case follows: Let the temperature of ebullition in the four cells be, see Fig. 5, 212° F., 203° F., 185° F. and 130° F.; let 1 lb. of steam enter cell 1 at 227° F. and let 6lbs. juice enter cell 1 at 212° F. and be of specific heat .9.



Then 1 lb. steam at 227° F. condensing and passing away to cell 2 at 212° F. gives up 975.2 B. T. U. and evaporates 1.006 lbs. water from and at 212° F.

There passes on to the calandria of cell 2 1.006 lbs. steam at 212° F. and 1 lb. water at 212° F.; there leaves the calandria of cell 2 2.006 lbs. water at 203° F. so that in all 978.8 B. T. U. have been surrendered which will evaporate from and at 203° F., 1.013 lbs. water; simultaneously 4.994 lbs. of juice pass into cell 2 from cell 1, and in cooling down from 212° F. to 203° F. they give up 4.993 × .9 × 9 = 40.5 B. T. U. corresponding to the evaporation of .042 lbs. water so that the total evaporation in cell 2 is 1.055 lbs. water. Proceeding on these lines the total evaporation in cell 3 is found to be 1.165 lbs. water and in cell 4 1.357 lbs. The final state of the apparatus is as follows:

Water at 130° F. discharged from calandria 4 = 4.226 lbs.

Vapor at 130° F. discharged from vapor space 4 = 1.476 lbs.

Syrup at 130° F. and .6 specific heat discharged from cell 4 = 1.298 lbs.

Water evaporated per lb. steam 4.702 lbs.

A diagramatic scheme of the system appears in Fig. 5.

Expressed per 1.000 unit of juice the final position is:

Juice at 212° F.	1.000
Condensed water at 130° F.	.704
Syrup at 130° F.	.216
Vapor at 130° F.	.246
Steam admitted at 227° F.	.167
Water evaporated	.784

The heat balance of the system appears as follows:

Delivered to Apparatus.

Juice	1.000 × .9 × 180	1620	
Steam	.167	1930	3550

Removed From Apparatus.

Syrup	.216 × .6 × 98	127	
Condensed water	.704 × 98	690	
Vapor	.246 × 1116.7	2747	3564

The ratio between condensed water and water evaporated will be very largely influenced by the initial temperature of the juice entering, that is to say by the value of J_0. The value 4.70 applies only to the conditions stipulated, namely J_0 212° F., J_4 and VS_4 and CW_4 130° F. the following table gives the variation in the values of $\frac{\text{water evaporated}}{\text{steam used}}$ for a variation in J_0 from 162° F. to 216° F.:

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* The temperatures selected for this example are unfortunate and give a greater value to $C_1 - C_2$ than to $C_2 - C_3$: with $C_1 = 227°$ F., C_2 should be about 217° F., so that $C_1 - C_2 = 10°$ F., and $C_2 - C_3 = 14°$ F. The calculation and cut for Fig. 5 were made before I noticed the slip, which does not affect in any appreciable way the result of the computation.

TABLE XXVII.

Temp. F. J_0	Max. possible Evap. per lb. of steam at 227° F. (C_1) and discharge (J_4) 130° F.	Temp. F. J_0	Max. possible Evap. per lb. of steam at 227° F. (C_1) and discharge (J_4) 130° F.	Temp. F. J_0	Max. possible Evap. per lb. of steam at 227° F. (C_1) and discharge (J_4) 130° F.
216	4.81	198	4.37	180	4.00
215	4.78	197	4.34	179	3.98
214	4.76	196	4.32	178	3.96
213	4.73	195	4.30	177	3.94
212	4.70	194	4.28	176	3.92
211	4.68	193	4.25	175	3.91
210	4.65	192	4.23	174	3.89
209	4.63	191	4.21	173	3.87
208	4.60	190	4.19	172	3.85
207	4.58	189	4.17	171	3.84
206	4.55	188	4.15	170	3.82
205	4.53	187	4.13	169	3.80
204	4.51	186	4.11	168	3.78
203	4.48	185	4.09	167	3.77
202	4.46	184	4.07	166	3.75
201	4.63	183	4.05	165	3.74
200	4.41	182	4.04	164	3.72
199	4.38	181	4.02	163	3.71

EXPERIMENTAL TESTS OF HEAT ECONOMY OF EVAPORATORS. The heat economy of five evaporators was determined, economy being defined as the ratio of $\frac{\text{water evaporated}}{\text{maximum possible}}$ as calculated in Table XXVII, taking into consideration the value of J_0 but neglecting other factors.

In the following tabulation all quantities are referred to the weight of juice entering which is put equal to unity. In the horizontal tube apparatus (Lillie film type) the evaporation in each cell was not determined and the value for the vapor found in cell 4 is approximated from the determinations in the other apparatus.

In obtaining the amount of water that present in the steam as found by calorimeter tests is deducted; the temperature values of the condensed water was not determined in all these experiments, but it is taken as that of the steam in the calandria whence it flows.

The experimental observations necessary for the determination of the heat economy of a multiple effect evaporator comprised:

1. Determinations of the density and temperature of the incoming juice.
2. Determinations of the volume, density and temperature of the outgoing syrup.
3. Determinations of the temperature and volume of the water discharged from the first cell.
4. Determinations of the temperature and quality of the steam, made as described on page .. •

The water from the first cell was often discharged at a temperature above 212° F. and consequently a certain amount of water evaporated on release from the trap. A correction was, when necessary, applied for this, as exemplified below: 420.3 c. ft. water were obtained, measured at 203° F. and discharged at 227° F. At 227° F. the total heat of water is 1155.5 B. T. U. and at 212° F. it is 1151.5 B. T. U.; at 212° F. the latent heat of evaporation is 966.5 so that the condensed water on discharging evaporates $\frac{4}{966.5} = .0041$ of its weight. At 203° F. 1 c. ft. of water weighs 60.2 lbs., so that the water collected is $420.3 \times 60.2 \div (1 - .0041) = 24{,}198$ lbs. The steam admitted to the first cell contained .2% water so the actual amount of condensed steam is 24,150 lbs.

It was found that no inconsiderable degree of accuracy could be obtained in duplicate determinations of the ratio $\frac{\text{water evaporated}}{\text{steam condensed}}$.

In a series with one evaporator the following consecutive results were obtained:

$\frac{\text{Water evaporated}}{\text{steam condensed}}$	J_0 F°	C_1 F°
3.408	192	230.9
3.375	190	232.1
3.372	190	231.1
3.353	188	229.9
3.392	192	231.3
Average 3.380	190.2	231.1

Six evaporators in all were tested with the following results: The apparatus in question are:

No. 1. Horizontal film evaporator, quadruple effect, 8906 sq. ft. heating surface evaporating at the rate of 5-6 lbs. per sq. ft. per hour; area exposed to radiation 2500 sq. ft. of which 2170 sq. ft. is protected with 1 inch asbestos and 330 sq. ft. is naked.

No. 2. Horizontal film quadruple effect evaporator of 9775 sq. ft. heating surface evaporating at the rate of 9-10 lbs. per sq. ft. per hour; area exposed to radiation 2800 sq. ft. of which all is unprotected.

No. 3. Horizontal submerged tube apparatus of 11,284 sq. ft. heating surface evaporating at the rate of 6-7 lbs. per sq. ft. per hour; area exposed to radiation 2950 sq. ft. of which 1670 sq. ft. is lagged with 1 inch asbestos and 1280 sq. ft. is bare.

No. 4. Vertical submerged tube quadruple effect evaporator of 12,521 sq. ft. heating surface evaporating at the rate of 5-6 lbs. per sq. ft. per hour; bodies lagged with wood and ½ inch air space; domes and pipes with 2 inches asbestos; total exposed area 2250 sq. ft., of which 2010 protected and 240 is bare.

No. 5. Vertical submerged tube quadruple effect evaporator of 14,146 sq. ft. heating surface evaporating at the rate of 9-10 lbs. per sq. ft. per hour; area of exposed surface 2750 sq. ft., of which 2460 lagged with 2 inches asbestos and ½ inch wood and 290 sq. ft. is bare.

No. 6. Vertical submerged tube quadruple effect evaporator of 8200 sq. ft. heating surface evaporating at the rate of 6-7 lbs. per sq. ft. per hour; exposed area 2580 sq. ft. of which 2300 is lagged with 1 inch asbestos and ½ inch wood and 280 sq. ft. is bare. The average results of the trials appear in Table XXVIII.

TABLE XXVIII.

	No. 1	No. 2	No. 3	No. 4	No. 5
Weight of juice	1.000	1.000	1.000	1.000	1.000
" " steam	.208	.239	.226	.234	.180
" " syrup	.279	.240	.232	.181	.225
" " water evaporated	.721	.759	.767	.819	.775
Water ÷ Steam	3.46	3.18	3.39	3.50	4.31
J_0 F°	189	180	190	175	214
C_1 F°	225	214	235	217	229
CW_1 F°	...	...	235	217	229
CW_2 F°	...	...	220	203	216
CW_3 F°	...	...	194	194	195
CW_4 F°	178	180	172	185	176
VS_4 F°	130	132	140	146	125
% evaporation in 1	...	...	19.3	20.0	19.7
% " " 2	...	...	18.1	20.3	18.5
% " " 3	...	...	19.6	20.5	18.8
% " " 4	(18.7)	(19.7)	19.6	21.1	20.5

A heat balance of these six evaporators appears as follows:

No. 1, average of twelve trials.
Total heat in
Juice = 1.000 × .9 = 1413
Steam = .208 × 1155 = 2402....3815 = 1.000
Condensed water from cell 1 = .208 × 193 = 402
" " " " 4 = .534 × 146 = 780
Syrup = .279 × .6 × 98 = 146
Vapor from cell 4 .187 × 1117 = 2089....3435 = .900
Unaccounted for 380 = .100
Economy .833

No. 2, average of two trials.
Total heat in
Juice = 1.000 × .9 × 148 = 1332
Steam = .239 × 1149 = 2746....4078 = 1.000
Condensed water from cell 1 = .239 × 182 = 436
" " " " 4 = .563 × 148 = 834
Syrup = .240 × .6 × 100 = 144
Vapor from cell 4 .197 × 1118 = 2202....3616 = .886
Unaccounted for 462 = .114
Economy .794

No. 3, average of twelve trials.
Total heat in
Juice = 1.000 × .9 × 158 = 142.2
Steam = .226 × 1159 = 261.9.... 404.1 = 1.000
Condensed water from cell 1 = .226 × 204 = 46.2
" " " " 2 = .193 × 188 = 36.3
" " " " 3 = .181 × 162 = 29.4
" " " " 4 = .196 × 140 = 27.5
Syrup = .232 × 6 × 108 = 15.1
Vapor from cell 4 196 × 1121 = 219.7....3742 = .926
Unaccounted for 29.9 = .074
Economy .809

No. 4, average of six trials.
Total heat in
Juice = 1.000 × .9 × 143 = 129.7
Steam = .234 × 1152 = 279.9.... 409.6 = 1.000
Condensed water from cell 1 = .234 × 185 = 43.4
" " " " 2 = .200 × 171 = 34.2
" " " " 3 = .203 × 162 = 33.0
" " " " 4 = .305 × 153 = 31.4
Syrup = .181 × .6 × 114 = 12.4
Vapor from cell 4 .211 × 1123 = 236.9.... 391.3 = .953
Unaccounted for 18.3 = .047
Economy .895

No. 5, average of three trials.
Total heat in
Juice = 1.000 × .9 × 182 = 163.8
Steam = .180 × 1156 = 207.1....3709 = 1.000
Condensed water from cell 1 = .180 × 197 = 35.5
" " " " 2 = .197 × 184 = 36.3
" " " " 3 = .185 × 163 = 30.1
" " " " 4 = .188 × 144 = 27.1
Syrup = 225 × .6 × 93 = 12.8
Vapor from cell 4 .205 × 1114 = 228.5....3703 = .999
Unaccounted for 6 = .001
Economy .905

No. 6, one trial.

In this trial only the value of J_0 and the ratio between steam used and water evaporated was determined; this latter was found to be 4.05 with juice entering at 202° F., giving an economy of .908.

Examination of these results shows a very marked difference between those apparatus which are covered with insulating material and those which are not so protected; the differences in the economy are, however, controlled also by the short circuiting of steam along with the incondensible gases.

EVAPORATIVE CAPACITY OF QUADRUPLE EFFECTS. During the course of these experiments opportunity was taken to determine the evaporative capacity under normal working conditions of a number of evaporators. The results of a number of tests are given below:

1. *Quadruple Effect Vertical Submerged Tube Apparatus.* The essentials of design in this apparatus are as below:

Heating Surface.—The heating surface is equally divided between the four bodies and is formed of copper tubes 2″ external and 1⅞″ internal diameter: the tubes are 48 inches long and number 2156 in each vessel. The vessels are 12 ft. 6 ins. in diameter and the central circulating tube is 4 ft. in diameter. The heating surface is then using the internal diameter* of the tubes:

$$\text{Tubes}\ \frac{3.14159 \times 1.875 \times 2516}{144} = \qquad 19760 \text{ sq. ft.}$$

$$\text{Tube plates } 8 \times [\,(67854 \times 12.5 \times 12.5) - (2516 \times .7854 \times 1/6 \times 1/6) - (.7854 \times 4 \times 4)\,] = \qquad 442 \text{ sq. ft.}$$

$$\text{Central Tube } 3.14159 \times 4 \times 4 \times 4 = \qquad 201 \text{ sq. ft.}$$

$$\text{Total} \qquad 20403 \text{ sq. ft.}$$

or 5101 sq. ft, per vessel.

Steam Distribution.—The distribution of steam or vapor (see Figs. 6 and 7) in each cell is obtained by means of a steam belt. B. 12 inches wide, completely surrounding the calandria. Steam or vapor enters in each vessel at two places separated from each other 90°—see A. Surrounding the tubular cluster are 40 distributing plates separated from each other ½″, 1½″, 2¼″, 3″ in the first, second, third and fourth vessels respectively. These plates are best perhaps described as a casing surrounding the

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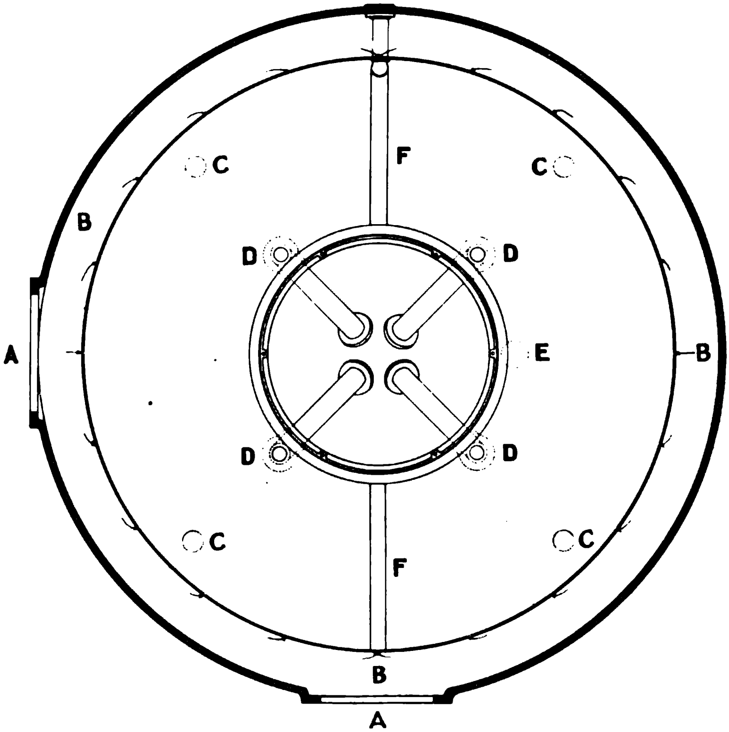
* The literature of the sugar cane is not well supplied with data on evaporator trials and I have come across no precedent establishing whether the heating surface should be calculated on internal or external diameter of tubes. The object of the apparatus is to transfer heat to the juice and as the juice in the apparatus is in contact with the tubes internally I think it more logical to consider the heating surface as that afforded by the inside of the tubes; actually the outside of the tube acts as a **condenser** and is therefore cooling surface: similarly in a horizontal tube apparatus as the Wellner-Jelinek or Swenson, in a film apparatus as the Lillie or in a Standard or helical coil pan, I think the external area of the tubes should be considered as heating surface.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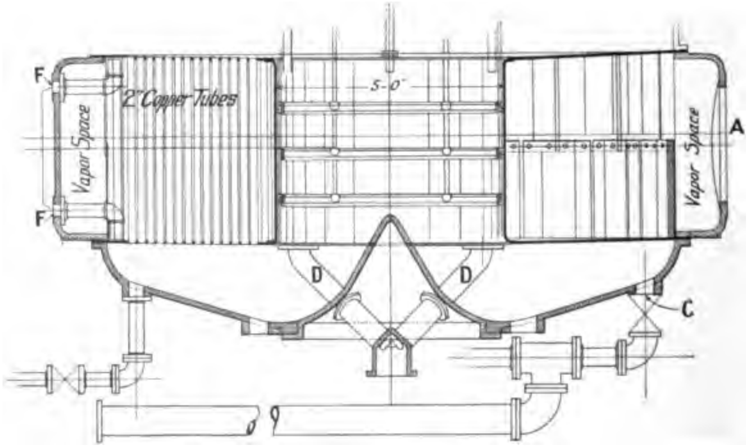

F
2" Copper Tubes
5-0"
Vapor Space
A
Vapor Space
F
D
D
C

tubular cluster and in which slots are cut of the width given above: the slots start alternately from top and bottom of the casing, a top or bottom slot being spaced midway between two bottom or two top slots: they terminate 3 inches above or below a mid point on the casing: they are then 1 ft. 9 ins. long. The area of the slots is:

Vessel I 40 × 1.75 × 1/24 = 2.92 sq. ft.
" II 40 × 1.75 × 3/24 = 8.75 " "
" III 40 × 1.75 × 9/48 = 13.10 " "
" IV 40 × 1.75 × 3/12 = 17.50 " "

Juice Distribution.—The juice is brought into each vessel from below and enters at four places near the periphery of the tubular cluster as shown at C: the juice is conveyed from vessel to vessel by one pipe and is collected at or near the periphery of the central circulating tube and at the side remote from one of the vapor inlets.

Calandria Drainage.—The drainage from the calandrias is taken away by four pipes, D. arranged around the periphery of the central circulating tube, the bottom tube plate being inclined from the circumference inwards to facilitate drainage. The condensed water from the first cell passes to the hot well of the boilers, that from the second, and following cells is passed from cell to cell and eventually to the calandria of the last cells whence it is discharged through a water leg.

Circulation.—The circulation in the evaporator is entirel yinduced. The lighter juice from a preceding cell entering at the bottom tends to rise through the more condensed juice already present, and thence to overflow down the central circulating tube, four feet in diameter; the slope of the saucer of a vessel is shown in Fig. 6 and its steep slope at the center probably aids the circulation.

Incondensible Gases.—The incondensible gases are trapped by two 2-inch pipes seen at F: the pipes carrying the gases taken from top or bottom of the tubular cluster unite, externally to an effect, into one, which then again enters the effect and terminates in the head box whence the gases pass to the vacuum pump; four one-inch pipes collecting gases from the under part of the tubular cluster are arranged round the periphery of the central circulating tube.

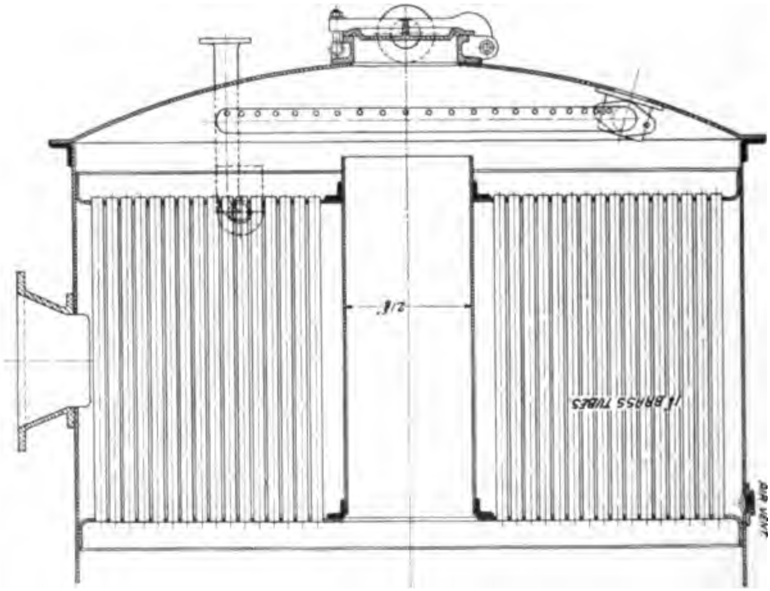
Condenser.—The vapors from the last effect were condensed on the dry vacuum system, the pumps being 24″ diameter and 20″ stroke and making 34 revs. per min.

The results of the trial were as below:

	Wednesday	Thursday
Temp. of Juice, F.°	210.5	212.0
" Calandria 1, F.°	225.5	227.7
" " 2, F.°	215.8	216.5
" " 3, F.°	202.7	203.5
" " 4, F.°	184.6	184.2
Vapor Space 4, F.°	127.0	129.7
Gross Temp. Diff., F.°	98.5	98.0
Brix Juice	15.23	14.57
Brix Syrup	60.12	58.72
Lbs. Juice	1,694,326	1,531,384
Lbs. Syrup	429,229	379,977
Lbs. Water Evap	1,265,097	1,151,407
Time, Hrs.	7.000	6.433
Lbs. Water per Sq. Ft. per Hr	9.03	8.84
Lbs. Water per Sq. Ft. per Hr. per 1° F. Temp. Diff	.0917	.0902
Vacuum Inches	25.7	25.4

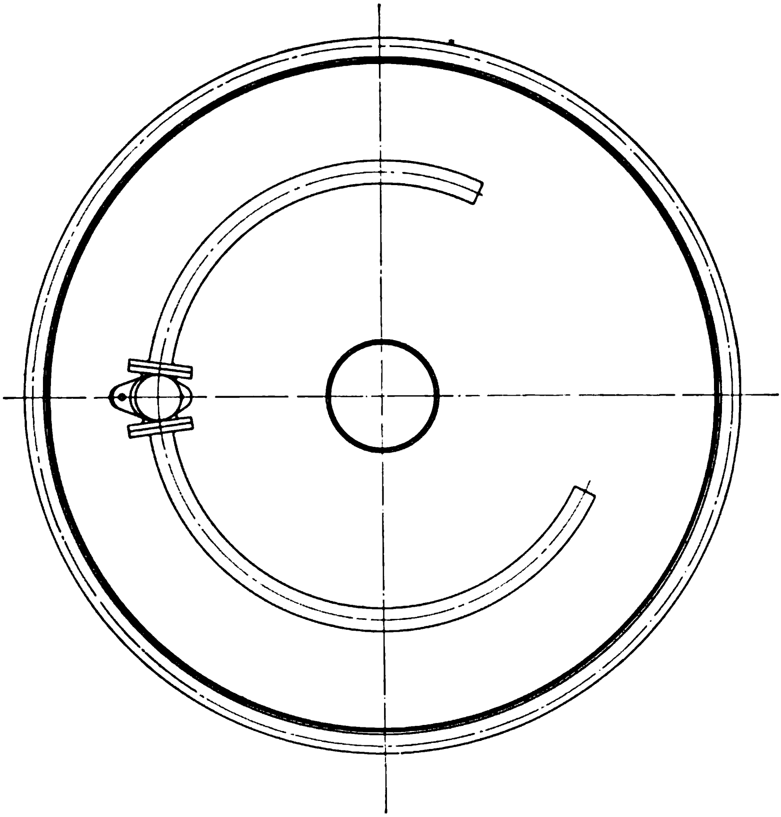
2. *Quadruple Effect Vertical Submerged Tube Apparatus.* The essentials of design in this apparatus are as below:

Heating Surface.—The heating surface is equally divided between the four bodies and is formed of copper tubes 1¾″ internal diameter and 52 inches long. The vessels are 9′ 6″ in diameter and the central circulating tube is 21½ inches. The total heating surface is 14,146 sq. ft.



Steam Distribution.—The steam to cell 1 enters at two places and goes direct to the calandria; see Fig. 8. In the other cells there is only one entry.

Juice Distribution.—The juice is fed into each cell from the bottom, being introduced through a pipe with one-inch holes spaced four inches apart, as shown in Figs. 8 and 9.



Vapor Pipes.—The vapor pipes were 23.5 inches, 27.4 inches, 31.3 inches and 35.2 inches in diameter.

Calandria Drainage.—The condensed water is voided from each cell separately and is not passed from cell to cell.

Incondensible Gases.—The incondensible gases pass directly from cell to cell and thence to the condenser; the exit of the incondensible gases in each cell takes place at one place only and at the surface of the upper tube plate remote from the entry of vapor. The results obtained were:

	Monday	Wednesday	Friday
Temp. of Juice, F.°	213.3	212.1	213.7
Calandria 1, F.°	228.4	228.9	228.4
" 2, F.°	216.1	214.8	217.0
" 3, F.°	194.9	194.6	194.3
" 4, F.°	174.4	174.4	176.2
Vapor Space 4, F.°	124.4	125.2	125.6
Gross Temp. Diff., F.°	104.0	103.7	102.8
Brix of Juice	15.10	13.00	14.10
" " Syrup	60.13	60.00	61.10
Lbs. Juice	199,226	828.085	266,610
Lbs. Syrup	50.078	179,446	61,530
Lbs. Water Evaporated	149,148	648,639	205,080
Lbs. Water Voided from Cell 1	34,754	148,633	49,450
Time, Hour	1.083	5.000	1.500
Lbs. Water Evap. per Sq. Ft. per Hr.	9.80	9.15	9.71
lbs. Water Evap. per Sq. Ft. per Hour per 1° F. Temp. Diff.	.0942	.0882	.0944
Vacuum Inches	26.5	26.6	26.0

The points of difference in the design of these two highly efficient apparatus are, so far as regards rate of evaporation:

Length of tube favoring No. 1.

Diameter of tube favoring No. 2.

Evacuation of condensed water favoring No. 2, since the water passed from cell to cell (unless it be very quickly evacuated) might bank up and cut off some heating surface.

Steam distribution favoring No. 1.

Size of vapor pipes favoring No. 1.

Size of circulating tube favoring No. 1.

Juice distribution according to individual ideas but the writer prefers the method used in No. 2. The performance of these two evaporators is in both cases very similar; No. 2 had the greatest temperature difference having a little excess over No. 1 at both the steam and vacuum end, but it is quite impossible to point to any difference in design as a prepondering factor in the performance.

No. 3. *Quadruple Effect Vertical Submerged Tube Apparatus.*

Heating Surface.—The heating surface was equally divided between the four bodies and was formed of copper tubes 4′ 6″ long 1⅝″ inside diameter. The vessels were 8 ft. 7½ ins. in diameter and the circulating tube was 20″ in diameter. The total heating surface was 12,521 sq. ft.

Steam Distribution.—The steam entered at two placed in cell 1 and in the other cells at one place only.

Juice Distribution was by a perforated pipe arranged at the bottom of the cells as in apparatus No. 2.

Vapor pipes were 26 inches diameter throughout.

In this test the following results were obtained:

				Mean
Temperature of juice, F.°	180.0	180.0	180.0	180.0
Calandria 1, F.°	219.2	221.5	222.0	220.4
Vapor Space 4, F.°	145.2	142.5	144.3	144.0
Lbs. per sq. ft hour	5.17	5.90	5.59	5.55
Gross Temp. Diff., F.°	74.0	79.0	76.1	76.4

At first sight this evaporator has done much less efficiently than either No. 1 or No. 2, but when the conditions under which it is working are looked into, namely the lower temperature of the steam, the higher temperature in the vapor space and the less gross temperature difference there is not so very much to choose. Referring to Table XVIII giving the results of a series of tests on the effect of vacuum the last list in that table was run with C_1 at 221.0° and VS_4 at 146.0°, conditions not dissimilar to those obtaining in the one under consideration; when, however, VS_4 was reduced to 125.6° F. (see Table XVIII) the rate of evaporation increased in the ratio .680 :903; supposing a similar increase occurred in this apparatus instead of an evaporation of 5.55 lbs. per sq. ft. per hour, with a 26.5 net vacuum an evaporation of 7.3 lbs. per sq. ft. per hour would be obtained with steam at 220.5. Now referring to Table XXV one of those dealing with the effect of increase in temperature of heating steam between 220.1° F. and 226.9° F., there is an increase in the rate of 495 : 562 and between 228.5 and 220.1 the increase would be in the nature of the ratio between say 47 : 56. On these particular determinations this apparatus with C_1 at 228.5 and VS_4 at 126.5 would be expected to evaporate at the rate of 8.7lbs.per sq. ft. per hour.

Further to make the comparison complete the difference in values of J_0 must be considered. With apparatus No. 3 J_0 was 180° F., with apparatus No. 2 J_0 was over 212° F. This difference may be regarded as so much heating surface taken away from the first cell; roughly I estimate this as of the nature of 500 sq. ft., which would for the purposes of comparison reduce the heating surface in apparatus No. 3 to 12,000 and increase the evaporation in lbs. per sq. ft. hour when compared on the same basis with apparatus Nos. 2 to 9.1 lbs., putting this apparatus on a very similar level with Nos. 1 and 2.

This correction must only be looked on as approximate as the experimental data are not regular enough for more than an indication of the order of the correction.

Apparatus No. 4. "Lillie" horizontal tube quadruple effect apparatus of 9775 sq. ft. heating surface.

The following data were obtained:

	Wednesday		Thursday	Friday
Temperature of juice, F°	179	179	179	179
Temp. of Calandria 1, F°.....	212.7	212.2	212.9	216.6
Vacuum inches..............	26.4	27.0	27.2	27.0
Temp. of Vapor Space, 4°F..	130	125	120	125
Gross Temp. Diff., F°	83	87	93	92
Brix juice	12.2	11.6	12.3	12.7
Brix syrup	60.6	61.85	61.55	59.8
Lbs. juice	111,538	53,690	59,782	63,813
Lbs. syrup	22,455	10.070	11,956	13,548
Lbs. water evaporated.......	98,083	43,620	47,826	50,265
Time, hours.................	1.00	.50	.50	.50
Lbs. water per sq. ft. hour...	9.12	8.92	9.78	10.30
Lbs. water per sq. ft. hour per 1°F. Temp. Diff.*...........	.109	.102	.105	.112

It will be seen that the results with two apparatus are higher than with the three apparatus first set out and are very remarkable when considered in connection with the low temperature of the heating steam.

SUMMARY.

1. A description of the methods employed in testing multiple effect evaporators is given.

2. The temperature difference in the first cell is a rough index of the rate of evaporation.

3. The vapors in a multiple effect evaporator are superheated.

4. The calculated effect of self-evaporation in a multiple effect evaporator is never realized, due to superheating of vapors and to short-circuiting of vapors with the incondensible gases.

6. Not only is the rate of evaporation influenced by the gross temperature difference, but it is also affected by the absolute temperature prevailing, increasing as this increases.

7. Increase of the gross temperature difference by means of decreasing the temperature at the cold end up to the temperature corresponding to a vacuum of 27 inches gives a material and valuable increase in the rate of evaporation, but this increase is not by any means as great as is obtained by a similar increase in gross temperature difference obtained at the hot end by increasing the temperature (or pressure) of the steam.

8. The heat economy of quadruple effect evaporators as found in practice compared with a computation on ideal lines lay between .8 and .9, this latter figure was found with well protected and the former with unprotected or badly protected apparatus.

9. A vertical submerged tube apparatus with 5 lbs. gauge pres-

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* Probable values: not observed in this experiment.

sure in cell 1 (227° F.) and not less than 26.5 inch vacuum in last cell (127° F.) should evaporate not less than 9 lbs. water per sq. ft. per hour, with juice entering at 212° F. and should evaporate 4.2 lbs. water per lb. of steam. If these conditions are not realized foul heating surfaces, too slow evacuation of condensed waters or incondensible gases, may be looked for.

10. A horizontal tube film evaporator had a much greater rate of evaporation than vertical submerged tube evaporators.

Fitz

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REPORT OF WORK
OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

The Heat Balance of a Cane Sugar Factory

BY NOËL DEERR

HONOLULU, HAWAII.
1914.

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Honolulu, T. H., Feb. 5, 1914.

To the Experiment Station Committee of the
Hawaiian Sugar Planters' Association.

Dear Sirs:—

I herewith submit for publication as Bulletin No. 43 of the Agricultural and Chemical Series, an article by Mr. Noel Deerr entitled, "The Heat Balance of a Cane Sugar Factory."

Respectfully,

H. P. AGEE,
Director.

THE HEAT BALANCE OF A CANE SUGAR FACTORY

By Noël Deerr.

In this publication is given an account of experimental work concerned with the above heading.

Although there have appeared in text books and in technical journals many detailed calculations of the amount of steam required at the various stations, experimental determinations have been largely absent

The headings considered here are:

1. The heat value of bagasse.
2. The steam generated by the combustion of the bagasse.
3. Steam required in evaporation in multiple effect.
5. Steam required in evaporation in single effect.
6. Heat represented by work.

The experimental work described in here was done in the factories of the Ewa Plantation Co. and the Oahu Sugar Co. From Mr. F. F. Campion, Mr. P. G. Messchaert and Mr. G. Bosse I received much assistance.

The Heat Value of Bagasse. The experimental work of Burwell, Hoogewerth, Koeing, and Bienfait supplemented by the very detailed studies of Norris on Hawaiian Bagasse have established the technical constancy of the heat afforded by cane fiber on combustion; following on his own determinations Norris accepts a mean value of 8100 B. T. U. per lb. of dry bagasse.

Steam Obtainable from Bagasse

The object of the trials described below was to actually determine what the furnaces and boilers were doing and to obtain a comparison of the performance of Babcock and Wilcox boilers and of smoke tube tandem multitubulars.

The Babcock and Wilcox boiler had 4000 sq. ft. heating surface and was provided with two grates each 51.75 sq. ft. area, giving a total grate area of 103.5 sq. ft. and a ratio of heating surface to grate area of 38.6:1; in marked distinction to this was the arrangement of the tandem multitubular boilers which contained 5224 sq. ft. heating surface and which had a grate area of only 48 sq. ft. or a ratio of 108.8 : 1.

The furnaces were of the Dutch oven type; during the trials the bagasse was fed by hand on to a scraper conveyor delivering the fuel directly into a hopper emptying on to the grate. In making the trials the bagasse was weighed out in quantities of 900 lbs. on a scale erected on the firing platform, a space about 30 ft. x 30 ft. being boarded off so as to allow of storage room; the water fed into the boiler was let down to the feed pump from rectangular tanks 4 ft. x 4 ft. and was measured to 1/16th inch depth, the temperature being simultaneously taken. The level of water in the boiler was made the same at start and finish and the quantity of bagasse in the furnace was very nearly the same at start and finish. Readings of the temperature of the feed water and of steam pressure were taken every 10 minutes; carbon dioxide was determined in the flue gases every 30 minutes and the quality of the steam was determined at the same interval with a throttling calorimeter. The essential data of the trials are scheduled below:

TRIAL NO. 1.

Boiler. Babcock & Wilcox; multitubular water tube.
Heating surface. 4000 sq. ft.
Grate. Step Ladder.
Grate area. 103.5 sq. ft.

$$\frac{\textit{Heating surface}}{\textit{Grate area}}\ 38.6$$

Fuel. Bagasse from 18 roller mill, water 45.9%, solids 2.5%, fiber 51.6%.
Calorific value of fuel. 8100 B. T. U. per lb. of dry matter
Duration of test. 414 minutes
Lbs. fuel burned. 39,366 lbs.
Lbs. water evaporated. 8,413 lbs.
Temperature of feed water. 170.0° F.
Steam pressure. 116.5 lbs. per sq. in gauge
Quality of steam. 98.8%.

$$\frac{\textit{Water evaporated}}{\textit{Fuel burnt}}\ (\text{Actual})\ 2.144.$$

$$\frac{\textit{Water evaporated}}{\textit{Fuel burnt}}\ (\text{from and at } 212^\circ\ \text{F.})\ 2.305$$

B. T. U. in steam per lb. of fuel burnt. 2234

$$\frac{\textit{B. T. U. in steam}}{\textit{B. T. U. in fuel}} = \frac{2234}{4382} = .509 = \text{Efficiency.}$$

Lbs. water per sq. ft. heating surface per hour. 3.06

Fuel burnt per hour. 5706 lbs.
Fuel burnt per sq. ft. grate area per hour. 55.1 lbs.
Fuel burnt per sq. ft. heating surface per hour. 1.43 lbs.
CO_2% flue gases. 13.4%=1.52 excess air

TRIAL NO. 2

Boiler. Babcock & Wilcox; multitubular water tube.
Heating surface. 4000 sq. ft.
Grate. Step Ladder.
Grate area. 103.5 sq. ft.

$$\frac{\textit{Heating surface}}{\textit{Grate area}}\ 38.6$$

Fuel. Bagasse from 18 roller mill, water 45.0%, solids 2.5%, fiber 52.5%
Calorific value of fuel. 8100 B. T. U. per lb. dry matter.
Duration of test. 404 minutes
Lbs. fuel burnt. 41872 lbs.
Lbs. water evaporated. 91408.
Temperature feed water. 168.0° F.
Steam pressure lbs. per sq. in. 115.3 (gauge)
Quality of steam. 99.0

$$\frac{\textit{Water evaporated}}{\textit{Fuel burnt}}\text{(actual) } 2.183$$

$$\frac{\textit{Water evaporated}}{\textit{Fuel burnt}}\text{(from and at } 212^\circ \text{ F.) } 2.351$$

B. T. U. in steam per lb. of fuel burnt. 2208

$$\frac{\textit{B. T. U. in steam}}{\textit{B. T. U. in fuel}} = \frac{2280}{4455} = .511 = \text{Efficiency}$$

Lbs. water per sq. ft. heating surface per hour. 3.39
Fuel burnt per hour. 6219 lbs.
Fuel burnt per sq. ft. grate per hour. 60.0 lbs.
Fuel burnt per sq. ft. heating surface per hour. 1.55
CO_2% flue gases. 14.92%=1.40 excess air
Temperature of flue gases. 631° F.

TRIAL NO. 3.

Boiler. Multitubular smoke tube set tandem
Heating surface. 2264+2960=5224 sq. ft.

Grate. Step Ladder.
Grate area. 48 sq. ft.
$\frac{\textit{Heating surface}}{\textit{Grate area}}$ 108.8
Fuel. Bagasse from 18 roller mill, 47.4% water, solids 2.7%, fiber 49.9%
Calorific value of fuel. 8100 B. T. U. per lb. dry matter
Duration of test. 350 minutes
Lbs. fuel burnt. 21985.
Lbs. water evaporated. 58630
Temperature of feed water. 171° F.
Steam pressure. (gauge) 100.0 lbs. per sq. in.
Quality of Steam. Not taken but assumed as 99%.
$\frac{\textit{Water evaporated}}{\textit{Fuel burnt}}$ (actual) 2.666
$\frac{\textit{Water evaporated}}{\textit{Fuel burnt}}$ (from and at 212° F.) 2.862
B. T. U. in steam per lb. of fuel burnt. 2775
$\frac{\textit{B. T. U. in steam}}{\textit{B. T. U. in fuel}} = \frac{2775}{4261} = .651 =$ Efficiency
Lbs. water per sq. ft. heating surface per hour. 2.04
Fuel burnt per sq. ft. grate area per hour. 78.5 lbs.
Fuel burnt per sq. ft. heating surface per hour. .74 lbs.
CO_2% flue gases. 15.0%=1.36 excess air

TRIAL NO. 4.

Boiler. Multitubular smoke tube, set tandem
Heating surface. 2264+2960=5224 sq. ft.
Grate. Step Ladder.
Grate area. 48 sq. ft.
$\frac{\textit{Heating surface}}{\textit{Grate area}}$ 108.8
Fuel. Bagasse from 18 roller mill, 47.4% water
Calorific value of fuel. 8100 B. T. U. per lb. of dry matter.
Duration of test. 350 minutes.
Lbs. fuel burnt. 21837
Lbs. water evaporated. 558145
Temperature of feed water. 160° F.
Steam pressure. 99.4 lbs. (gauge)
Quality of steam. Not taken but assumed at 99%

$\frac{\textit{Water evaporated}}{\textit{Fuel burnt}}$ (actual) 2.556

$\frac{\textit{Water evaporated}}{\textit{Fuel burnt}}$ (from and at 212° F.) 2.768

B. T. U. in steam per lb. fuel burnt. 2684

$\frac{\textit{B. T. U. in steam}}{\textit{B. T. U. fuel}} = \frac{2684}{4261}$ =.629=Efficiency

Lbs. water per sq. ft. heating surface per hour. 1.98

Fuel burnt per sq. ft. grate area per hour. 77.9 lbs.

Fuel burnt per sq. ft. heating surface per hour. .71 lbs.

CO_2% flue gases. 15.4=1.34 excess air

Temperature of flue gases. 434° F.

Before discussing the results a definition is required for the efficiency of a bagasse fuel and this is discussed below.

The calculation of the efficiency of a bagasse fired furnace and boiler is rather complicated; in the combustion of bagasse or of any carbohydrate fuel a considerable proportion of water is formed and in the calorimeter the water appears as such and after having been originally present as steam gives up its latent heat; in a bagasse furnace the water formed on combustion passes away in the flue gases as steam and hence its latent heat which appears and is accounted for in the determination of the heat of combustion in the calorimeter can never be obtained in practice. Thus if a dry bagasse containing 6.5% hydrogen in the calorimeter gives a heat of combustion of 8100 B. T. U. it affords on combustion 58.5% of water; the difference in the total heat of water at 84° F. and steam at atmospheric pressure at 550° F. is very closely 1300 B. T. U.; thus the water of combustion of 1 lb. of dry bagasse will in general practice carry away $.585 \times 1300 = 770$ B. T. U. and the realizable thermal value of the pound of bagasse will be 770 B. T. U. less than the actual thermal value as determined from calorimeter tests.

Secondly, there is the question of the treatment of the water of association which also will with flue gases at 550° F. carry away very closely 1300 B. T. U. per lb; it may be argued that this quantity should be deducted from the thermal value in calculating the efficiency. There are then three bases of calculation:

(a) The actual heat of combustion.

(b) The quantity in (a) less the heat lost in the associated water assuming some definite flue temperature.

(c) The quantity in (b) less the heat lost in the water of combination assuming some definite flue gas temperature

A bagasse of composition water 45.9, solids 54.1, will have from Norris' determinations

$$8100 \times .541 = 4382 \text{ as the gross thermal value.}$$

Under the definition (b) the value will be with flue gases at 550° F. $8100 \times .541 - 1300 \times .459 = 3785$ B. T. U.

If the dry bagasse contain 6.5% hydrogen the water of combination will be $.065 \times .341 \times 9 = .316$ and the value will be

$$8100 \times .541 - 1300\ (.459 \times .316) = 3375 \text{ B. T. U.}$$

The writer is of the opinion that the most rational basis of comparison is that defined under (a) as he sees no grounds for treating the losses due to associated water and combined water as different from those due to excess air and carbon dioxide and accordingly in the annexed schedules the actual heat of combustion is taken as the basis of calculation of the efficiency; the efficiency of a bagasse fuel will always on this basis be lower than that of a coal or oil fuel.

Taking the average of the trials it will be seen that the tandem boiler evaporated 2.815 and the Babcock & Wilcox boilers 2.328 lbs. water per pound bagasse from and at 212° F.; this gives a superiority in so far as regards steam per lb. of fuel of 20%; this increased economy is to be attributed solely to the much greater proportion of heating surface per pound of fuel burnt; in the tandem boiler only .72 lb. fuel was burnt per sq. ft. heating surface per hour as compared with 1.49 lbs. in the Babcock & Wilcox boiler; in other words, the Babcock & Wilcox boiler steamed nearly twice as fast as the tandem smoke tube boiler but was 20% less efficient as regards economy and this statement expresses concisely the result of the trial. It may be remarked that the efficiency of combustion as evidenced by the percentage CO_2 in the flue gases is very much the same and the superiority in economy found with the tandem boiler is simply due to the greater reduction in the temperature of the products of combustion due to the larger heating surface.

The efficiency of a furnace with over 15% CO_2 in flue gases is very high and the combined efficiency of the tandem boiler and furnace is exceptionally high, while the results obtained with the Babcock & Wilcox installation though lower are, I believe, still well above the average.

A comparative heat account of the two installations is given below: it will be seen that with the tandem boilers the heat unaccounted for in steam and flue gases is very small, but that in the Babcock & Wilcox boiler it is comparatively high; the better utilization of the heat contained in the products of combustion in the tandem setting as evidenced by the lower flue gas temperature is not sufficient to account for the very superior results, consequently the difference goes to swell the unknown or radiation loss in the Babcock & Wilcox installation; from the inspection of the furnaces I was expecting a larger radiation loss with the tandem setting than with the Babcock & Wilcox installation. It will be seen that the bagasse burnt under the Babcock & Wilcox boiler contained 2% less water than that burnt under the tandem setting and quite probably an error may have been introduced in the sampling or analysis and any error will appear entirely in the unknown or radiation loss. The actually found figures follow below:

	Babcock & Wilcox.	Tandem.
Total B. T. U. per lb. fuel.........	**4499 = 100.0**	**4261 = 100.0**
In steam	**2257 = 51.0**	**2730 = 60.0**
In flue gases	**1621 = 36.7**	**1292 = 30.3**
Radiation, &c	**541 = 12.3**	**239 = 3.7**

The results given below are in one particular liable to misinterpretation. The fire tube tandem boilers afforded per pound of bagasse 20% more steam than did the Babcock & Wilcox water tube boilers; this is *not* to be taken as implying that fire tube boilers are more economical steam generators than are water tube boilers, but the result applies to this particular installation only and includes the effect of the furnace, of the combustion, and especially the quantity of "fuel burnt per square foot of heating surface."

In all the trials the combustion as judged by the percentage of carbon dioxide in the flue gases was equally good; the water tube boilers gave 3.17 lbs. water evaporated per square foot heating surface per hour as compared with the 2.01 lbs. with the fire tube tandem boilers If either the heating surface in the Babcock & Wilcox boilers were increased or the quantity of fuel burnt were decreased, it is certain that a greater generation of steam per pound of fuel would be obtained and results equal to those from the tandem fire tube boilers would follow, but then in the latter case steam would not be generated fast enough to serve the factory. A comparison of the relative efficiency of heating surface of the water tube boiler in this installation can be made on the following lines: With a percentage of carbon dioxide in flue gases over 15% the temperature of combustion will be approximately 2700° F. The final temperature of the flue gases in the Babcock & Wilcox installation was found to be 631° F. and the temperature in the boilers is 350° F. The mean temperature difference is then found as follows:

Temp. max. $2700-350=2350$
Temp. min. $630-350=281.$

$$\frac{\text{Temp. min.}}{\text{Temp. max.}}=\frac{281}{2350}=.119$$

$$\text{Mean temp. difference}=\frac{2350\left(1-\frac{11.9}{100}\right)}{\log_e\frac{100}{11.9}}=982$$

For the fire tandem boiler the corresponding figures are:

Temp. max. $2700-340=2360$
Temp. min. $434-340=94$

$$\frac{\text{Temp. min.}}{\text{Temp. max.}}=\frac{94}{2360}=.0398$$

$$\text{Mean temp. difference}=\frac{2360\left(1-\frac{3.98}{100}\right)}{\log_e\frac{100}{3.98}}=703$$

As an average the Babcock & Wilcox boilers with 4000 square feet heating surface evaporated 3.22 lbs. water per square foot per hour, and the fire tube tandem boilers with 5224 square feet evaporated 2.01 lbs. per square foot per hour. The pounds water evaporated per hour per 1° F. temperature difference is then

Babcock & Wilcox boiler	**Fire tube tandem boiler**
$\frac{3.22}{982}=.00329$	$\frac{2.01}{703}=.00286$

and the efficiency of heat transmission of the Babcock & Wilcox boiler is $\frac{329}{286}=1.15$ times as great as is the efficiency of the fire tube tandem boilers.

Further as regards these trials there is one more point which is to be strongly insisted on; as an average the fire tube multitubular boiler afforded 2.6 lbs. steam per lb. bagasse, the heating surface in these boilers is from 650-700 sq. ft. per short ton cane hour. This is a very much larger allowance than usually found and consequently in the general run of cane sugar factories so large a quantity of steam will not be capable of being produced. Nevertheless as a standard basis the writer holds that experimentally under actual working conditions this production is established. This quantity of heating surface is much larger too than ordinary practice as given in text books allows, but the standard engineering text books are generally written from the point of view of cheaper fuel and more valuable floor space; in the cane sugar industry fuel is dear and floor space is worthless and hence the writer believes that capital expended in ample heating surface will always be a profitable investment.

Finally these trials may at once dispose of the superstition that multiple crushed bagasse has a lower fuel value than bagasse not so treated.

Heat Used in Engines. In a cane sugar factory a certain amount of steam S enters the cylinders of the engine at a pressure P and a certain amount s leaves at a pressure p, accompanied by a certainty of water W condensed in the cylinder. Determining the quantities will give data to translate into bagasse the heat actually used in the engines.

The method adopted to determine these quantities was by indication of the engines combined with certain calorimeter tests. The following results were obtained:

No. 1. *Cane Engine.* Corliss 22″x48″ driving cane carrier, crusher and first mill 34″x78″, with hydraulic load at 400 tons; cane was being worked at the rate of 100,000 lbs. per hour and contained 12.7% fiber or 12,700 lbs. fiber* per hour. Gauge pressure 105-110, exhaust 5-10 lbs. per sq. in.; engine working 45 r. p. m. The results of ten cards are given below:

	M. E. P. Lbs. sq.in	Cut Off.	I. H. P.	I. H. P. t. c. h.	I. H. P. t. f. h.
Max.	53.8	.28	218	4.36	34.3
Min.	41.1	.18	166	3.33	26.2
Mean	45.3	.21	184	3.68	28.9

No. 2. *Cane Engine.* 28″x48″ Corliss driving three mills 34″78″ with hydraulic loads 400 tons on each mill; other data as for No. 1 engine.

	M. E. P Lbs. sq.in.	Cut Off.	I. H. P.	I. H. P. t. c. h.	I. H. P. t. f. h.
Max.	63.6	.40	443	8.86	69.8
Min	48.2	.23	332	6.64	52.2
Mean	53.9	.28	372	7.44	58.7

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* It is self-evident that mill power data should be referred, not to tons cane per hour, but to fiber per hour; it is compression of the fiber which absorbs the power, and with variation in the fiber % cane from 10 to 14, it is apparent that equal quantities of cane may mean very different quantities of fiber.

Combining the results from the two engines, the power received to crush a ton of cane and fiber per hour, including therein the working of the cane carrier, and all appurtenances but not discharging from cars, in a 12-roller mill appears as under:

	I. H. P. t. c. h	I. H. P. t. f. h.
Max.	13.22	104.1
Min.	9.97	78.4
Mean	11.12	87.6

As always there must be available some excess of power, this result may be expressed: In a 12-roller mill and crusher plant there should be available in the motors at least 100 H. P. for every short ton of fiber to be crushed per hour.

Evaporator. The evaporator was a quadruple effect of 14,146 sq. ft. heating surface, and capable, with 5 lbs. initial pressure, of evaporating more than 9 lbs. per sq. ft. per hour, the vacuum (dry) was obtained by a slide valve pump, 3½"x31½", driven by engine 16¼"x31½" fitted with Meyer expansion gear and making 46 r. p. m. The I. H. P. was 27.6.

Pan No. 1 was of 2455 sq. ft. heating surface; the pump was a duplicate of the one used with the evaporator, and it indicated 27.9 H. P.

Pan No. 2 was of 1002 sq. ft. heating surface; the pump was 23½ x21⅝", driven by engine $12\frac{15}{16}$"x21⅝" and made 52 r. p. m.; it indicated 15.2 H. P.

Crystallizers. At the time of making the test there were in motion 15,700 c. ft. of massecuite, the full capacity of the house; the stirrers were making ½ revolution per minute. The engine was of a Meyer expansion type 13¾"x$27\frac{7}{16}$", making 45 r. p. m.; it indicated 16.5 H. P., or 1.05 H. P. per 1,000 c. ft. of massecuite and .255 H. P. per ton of cane per hour, taking the capacity of the house at 65 t. c. h.

Centrifugals. There were sixteen 42" machines driven by two direct acting duplex pumps; No. 1 pump had the H. P. cylinder 14"x10", and the L. P. cylinders 20"x10", and made 46 strokes per minute. It indicated 39.1 I. H. P. No. 2 pump had the H. P. cylinders 12"x14½" and the L. P. cylinders 17"x14½"; it indicated 33.7 I. H. P. The total H. P. developed is 72.8, or

4.55 H. P.* per machine and 1.12 H. P. per t. c. h. on a basis of 65 tons of cane per hour. It is to be noted that this 4.55 H. P. per machine is the power developed by the prime motor when the machines were working normally, some starting, some discharging, some at full speed, some accelerating, some slowing down; it does not denote the power required to run a machine at any particular moment, but is the average power developed to run the whole battery under normal full capacity.

Heater Pump. The pump forcing the juice through the juice heaters at the rate of about 110,000 lbs. juice per hour developed 3.8 I. H. P.

Supplementary Engines. The direct steam from the boilers was also used to drive.

1. A direct acting steam pump which was found to indiacte 61.6 I. H. P.

2. A Mackintosh Seymour engine 24″x25″, running at 200 r. p. m. and driving an electric generator supplying power for pumping, carpenter and machine shop and electric lighting; it was actually developing 87 I. H. P., much below its rated capacity; the exhaust from these engines was, of course, returned to the boiling house. The remaining prime motors, boiler feed pumps, juice pumps, magma pump, etc., were not indicated.

The H. P. developed at the stations connected with the sugar factory proper are then expressed per 65 tons cane per hour, per 70 tons juice per hour, per 8.5 tons sugar per hour.

Mills	723	
Quadruple pump	28	
Pan pumps	43	
Crystallizers	16	
Centrifugals	72	
Heater pump	5	
Add for other motors	30	
Total	917	I. H. P. or 14.1 I. H. P. per t. c. h.

The above pages give the actual horse power developed; the steam and heat consumed in the engines were found as follows:

From the usual methods of computation of the steam consumption, I found that a H. P. hour was produced with 24 lbs. steam. In making the computation I took a point close to the exhaust point, so that the computation means that 24 lbs. of exhaust steam were produced per I. H. P. To know how much steam entered the cylinder required a knowledge of the quality of the exhaust steam, and this I determined as follows:

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*Of the No. 1 machines there are always six in operation at a time; never more than that.

The Carpenter separating steam calorimeter can not be used for pressures below 25 lbs. per sq. in., not because the separation of water is ineffective, but because Napier's formula for the flow of steam through an orifice is not sufficiently exact for low pressure. I, however, used a Carpenter separating calorimeter as follows: The instrument was attached to the exhaust pipe and exhaust steam passed through; the *dry separated* steam was condensed in a bucket of cold water, the quantity being determined by weighing before and after passing steam. The separated water was run out from the instrument, caught in a beaker and weighed. I believe in this way very exact determinations of the quality of low pressure steam can be made and at much less trouble than the usual method:—condensation of steam in water and thermomometric observations.

As a result of my trials I found that the steam exhausted from the cane engines contained 21.6% of water, calculated on the steam condensed. I had already found that 24 lbs. steam were exhausted per I. H. P., so that the boiler steam admitted is 1.216 ×24=29.2 lbs. per I. H. P. Now, this steam reached the engines very nearly dry and at 100 lbs. gauge. The total heat of steam at 100 lbs. gauge is 1,188.5 B. T. U., so that per I. H. P. there are supplied to the cane engines 1,188.5×29.2=34,705 B. T. U. The total heat of steam at 5 lbs. gauge is 1,155.9, so that the engines deliver 24×1,155.9=27,742 B. T. U., a loss of 6,963 B. T. U. per I. H. P. Per 50 t. c. h. the mill engines developed 556 I. H. P., so that the heat actually used at this station is 3,864,000 B. T. U. Now, 1 lb. of bagasse will give net, as represented in the steam generated, from 1,800 B. T. U. (very low) to 2,800 B. T. U. (excellent). Taking the last figure, the 3,864,000 B. T. U. actually consumed by the cane engines will be represented by 1,350 lbs. bagasse, and if the first figure be taken by 2,140 lbs. bagasse. Fifty tons of cane afford 25,000 lbs. of bagasse, so that the actual consumption of bagasse by the mill engines lies between 5.4% and 8.6% of that available, depending, of course, on the efficiency of the steam generating plant.

It was found above that per ton cane hour the motors in a modern well-equipped mill consumed 14.1 H. P. This figure was obtained with cane with 12.7% fiber, and actually it is the fiber in cane which is the dominant factor controlling the consumption of power. I have shown here that, based on experimental figures, each horse power hour is developed with a consumption of 6,963* B. T. U.; that is to say, with a consumption of 3.8 to 2.4 lbs. bagasse, provided, of course, that the power is developed by engines of similar economy to those used at the mill; then per ton of cane hour from 34 to 54 lbs. of bagasse will be required to provide power. One ton of cane will produce about 500 lbs. bagasse, so that the power requirements of a sugar mill are represented by from 6.8% to 10.8% of the bagasse.

The data at hand are sufficient to solve problems such as the following: A plant consisting of a crusher and nine-roller mill working 50 t. c. h. is to be increased to a twelve-roller mill. What will be the extra consumption of steam and of bagasse, it being known that each pound of bagasse in this mill affords 2.4 lbs. steam at 100 lbs. gauge? Already it had been found that a nine-roller mill took 7.44 H. P. per t. c. h., or 2.81 H. P. per ton cane hour per mill. There will then be required 140 H. P. more power, which will be afforded by 140×29.2=4,088 lbs. steam put into the cylinder of the engine, of which 140×21=3,360 come out as exhaust, leaving 728 lbs. to be made up by the bagasse. This will be done by 331 lbs. of bagasse. This does not allow for the difference in heat value between boiler pressure steam and back pressure steam and for additional piping, but these losses will be amply covered by taking 350 lbs. of bagasse in place of 331. Fifty tons cane afford 25,000 lbs. bagasse, so that the increased output of steam required is 1.4%—a very small quantity.

Heat Used in Heating Juices. This station was not examined experimentally and although a large consumer of steam. in the light of the other determinations no sensible error will be introduced by calculation. To raise 1 lb. juice of specific heat .9 from 80 to 212° F. will take 132×.9=118.8 B. T. U., a quantity afforded by the condensation of .124 lbs. steam at 5 lb. gauge; allowing in the view of the experimental data obtained with the pan and multiple an efficiency of .95, a consumption of .131 lb. steam is indicated.

Reheating Juices. The temperature at which the juice will enter the multiple evaporator will depend on the efficiency of the lagging of the juice containers; 205° F. can be obtained in well covered containers and 180° F. in inefficient ones. As this heat balance is concerned with the determination of technically efficient factors and not with inefficient ones, the higher value is accepted. Let the first cell of the multiple effect boil at 212°

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* I am referring to the heat actually consumed in the engine, and in a sugar mill the balance is available for evaporation.

F., then the heat required per lb of juice is 7×.9=6.3; afforded by .066 lb. steam at 5 lbs. gauge and at 95% efficiency by the consumption of .069 lb. of steam.

The heating and reheating of the juices then may be taken as requiring .200 lb. steam at 5 lbs. gauge per 1 lb. of juice.

It is worth while noticing that a fall in temperature in juices before entering the multiple effect means a four-fold loss in the case of a quadruple for steam used on heating the juice to the temperature of ebullition in the first cell is not used at multiple effect.

Heat Used in Multiple Effect Evaporation. The heat economy of multiple effect evaporation in so far as regards a number of quadruple effect evaporators was discussed fully in Bulletin 42.

An abstract of the results obtained there calculated to juice entering the apparatus at 212° is given below.

The pounds of water evaporated per lb. of steam at or near to 5 lbs. gauge were found to be:

1. Horizontal tube film evaporator 8906 sq. ft. heating surface; 330 sq. ft. bare exposed area, 2170 sq. ft. covered with 1 inch asbestos; 3.85.
2. Horizontal tube film evaporator 9775 sq. ft. heating surface; 2800 sq. ft. exposed area, all unprotected; 3.64.
3. Horizontal submerged tube evaporator of 11,284 sq. ft. heating surface, 1280 sq. ft. unprotected exposed area and 1670 sq. ft. covered with 1 inch asbestos; 3.78.
4. Vertical submerged tube evaporator, 12,521 sq. ft. heating surface; 240 sq. ft. unprotected area, 12,010 sq. ft. protected by 2 inches asbestos and by ½ inch air space and wood; 4.13.
5. Vertical submerged tube evaporator 14,146 sq. ft. heating surface; 290 sq. ft. bare and 2460 sq. ft. protected with 2 inches asbestos and ½ inch wood; 4.31.
6. Vertical submerged tube apparatus of 8200 sq. ft. heating surface; 250 sq. ft. unprotected area and 2500 protected with 1 inch asbestos and ½ inch wood; 4.23.

Steam Used in Vacuum Pan lb. of Water Evaporated. A trial gave the following results: Lbs. syrup sent to pan at 64.23 Brix and 115° F. and .45 sp. heat=210.067. Lbs. massecuite at 162° F., 87.27 Brix and .39 sp. heat=154.625. Lbs. water condensed, 55.386.

Steam pressure 90 lbs. gauge on main steam line to pan.

Temperature in discharge lines from pan, 240° F.

The condensed water in the discharge lines is under pressure and on reaching the atmosphere part of the water disappears as steam. Water at 240° F. has a total heat of 1162.7 B. T. U., and at 212° F. one of 1150.0 B. T. U.; the water as measured must then be increased by 1.1% or by 608 lbs. to allow for this, making the total quantity of condensed steam 55,994 lbs. discharged at 248° F.

The lbs. of water evaporated are 210,067—154,625=55,442, giving an evaporation of .988 lbs. water per lb. steam at 90 lbs. gauge.

The heat balance of this trial appears as under:

Heat admitted to pan:

55,994 lbs. steam at 90 lbs. gauge=55,442×1181=661,800,000 B. T. U.

210,067 lbs. syrup at 115° F. and .45 sp. heat=210,067×.45×83=7,850,000 B. T. U. Total, 669,650,000 B. T. U.

Heat delivered from pan:

154,625 lbs. massecuite at 162° F. and .39 sp. heat=154,625×130×.39=	7,840,000 B. T. U.
55,994 lbs. water at 240° F.=55,994×216=	12,090,000 "
55,442 lbs. vapor at 135° F.=55,452×1119=	620,500,000 "
Total	640,430,000 B. T. U.

The experiment gives 95.8% of the heat admitted to the pan as accounted for.

There is sufficient data here available for the construction of an experimental heat balance of two typical cases, first a factory or high efficiency* and secondly one of high but not by any means of exaggerated inefficiency.

1. From 100 short tons cane let there be produced 50,000 lbs. bagasse and 110 short tons of juice; the combustion of the bagasse under boilers of sufficient heating surface will produce 50,000×2.6=130,000 lbs. steam corresponding to an efficiency of about .65.

2. *Power.* If the 100 tons cane be milled in one hour there will be required 1410 I. H. P., which were found to be obtained per I. H. P. with the consumption of 5.2 lbs. steam or 7330 lbs. of steam or 5.6% of the steam coming from the boiler.**

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* The system of heating and evaporating here considered does not include the extra steam or pre-evaporation systems, so that the economy and efficiency is not by any means the highest possible; this publication is treating of experimental results as they occurred.

** This 5.2 lbs. is of course the steam used in cylinder condensation and work and the loss of heat between the boiler and exhaust pressures is not taken into consideration.

3. *Heating and Reheating.* Let the juice be heated from 82° F. to 212° F., cool to 202° F. and be reheated to 212°. F. before it enters the quadruple effect evaporator, in all through 140° F.; the consumption of steam will be:

$$\frac{140 \times .9 \times 220{,}000}{960 \times .95} = 30{,}590 \text{ lbs. steam,}$$

accepting .95 efficiency and letting the condensed steam flow away at the temperature corresponding to the gauge pressure; this is 23.4% of the steam coming from the boilers.

4. *Quadruple effect.* Let the juice be of 13° Brix and the syrup 65° Brix; then the quadruple removes 176,000 lbs. water, with a consumption of $\frac{176{,}000}{4.2}$ =41,850 lbs. steam or 32.5% of the steam coming from the boilers.

5. *Pans.* There will remain approximately 15,000 lbs. water to be removed in the pans, which will require $\frac{15{,}000}{.988}$ =15,182 lbs. steam or 11.6% of the steam coming from the boilers.

The total of these five stations is 94,952 lbs. steam or 73.1% of that coming from the boilers.

In the second case let there again be 100 tons cane producing 50,000 lbs. bagasse and 110 tons juice and let the bagasse only produce 110,000 lbs. of steam.

1. *Power.* Let this remain unchanged and as before let 7330 lbs. of steam be used at this station or 6.7% of that coming from the boiler.

2. *Heating and Reheating.* Let the juice cool to 172° F. before entering the evaporator; the range of heating and reheating is now 170° F. and will require

$$\frac{170 \times .9 \times 220{,}000}{960.1 \times .95} = 37{,}145 \text{ lbs. steam or } 28.6\% \text{ of that}$$

coming from the boilers.

3. *Quadruple Effect.* Let the evaporation be only carried to 60° Brix from juice of 13° Brix entailing the removal of 172,332 lbs. water with the consumption of $\frac{172{,}332}{3.8}$ =45,350 lbs. steam or 41.2% of that coming from the boilers.

Pans. There will remain approximately 18,500 lbs. water to be removed in single effect which will require $\frac{18{,}500}{.95}$ =19,470 lbs. steam, taking a less heat efficient pan than in the first case; this is 17.7% of that coming from the boilers.

The total of these quantities is 109,295 lbs. or 99.3% of that coming from the boiler. Under these circumstances a factory in this condition might just get along without extra fuel; the first type of factory would have a great surplus, which could be used for other purposes.

Finally it may be pointed out that the heat balance of a cane sugar factory will depend on a multitude of factors so that an analysis is required of each individual factory. The factors without the control of the factory executive are:

1. Fiber in cane, controlling the steam available.
2. Sugar in cane, controlling the amount of evaporation to be done at single effect and at multiple effect.

The factor under the control of the factory executive is:

Efficiency of the factory including therein, heating surface in boilers and control of the combustion, protection of hot surfaces, sufficient heating surface in evaporators to obtain not less than 65° Brix in syrup and arrangement of plant to allow of the use of extra steam and of multiple heating.

Experimentally determined data have been given in this publication bearing on these matters.

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AGRICULTURAL AND CHEMICAL SERIES

BULLETIN No. 44

REPORT OF WORK
OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

The Implements of the Industry

BY H. P. AGEE

HONOLULU, HAWAII
1914

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LETTER OF TRANSMITTAL.

To the Experiment Station Committee
of the Hawaiian Sugar Planters' Association,
Honolulu, Hawaii.

Dear Sirs:—Herewith I submit for publication, as Bulletin No. 44 of the Agricultural and Chemical Series, some notes which I have brought together under the title of "The Implements of the Industry."

Respectfully,

H. P. Agee,
Director.

Honolulu, Hawaii, April 25, 1914.

PREFACE

This bulletin is intended to be corollary to the annual reports of the committees which have to do with new developments in cultural practices.

The present compilation goes a step without the scope of those committees—a step backward if you will—in an effort to bring together any ideas, be they new or old, that have to do with implement cultivation of sugar-cane in these Islands.

There is still such an amount of hand-hoeing on the plantations of this Association that a conspicuous opportunity for economy arises if such labor can be materially reduced. Any means to this end, that has stood the test of practical utility, should be worthy of consideration. Hence this account of a number of implements found in service, assembled without selection, and assigned to the cause of putting a more effective device into the hands of the man with the hoe.

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THE IMPLEMENTS OF THE INDUSTRY.

By H. P. Agee.

INTRODUCTORY.

Any well directed attempt at improving agricultural methods should begin with a detailed study of those methods as they exist. Concerted action upon such a problem should start by ascertaining what individual efforts have been made. Most of all we wish to record attempts that have proved sufficiently satisfactory to become practical routine.

The extent to which implement work may eventually replace the large amount of hand labor that still appears so essential is an open question. If it were another instance of judging the future by the past, it would be encouraging to gauge it by the extent to which the implement work of today substitutes the hand work of a decade or more ago.

What each plantation has done on this score could no doubt best be told for the benefit of all by each plantation. But since we have undertaken to summarize, for the benefit of each, what the plantations as a whole are doing in this regard, we proceed with due acknowledgment of many courtesies extended us in collecting these notes, and due apology for whatever individual credit we may fail to record.

Implement work has gained its strongest hold in the districts of heavy rainfall where hand weeding is most irksome and expensive, and relief most essential to the continued welfare of the plantations. Here again ingenuity answers the call of necessity. As the labor supply becomes more restricted other plantations adopt certain implements. Some plantations which have insufficient rainfall to do without irrigation, yet ample rainfall to cause a heavy weeding expense, are finding implements well suited to their needs. Urged by the pinch of circumstance we are gradually becoming aware that irrigation and implement cultivation are not so incompatable as we once thought them.

Many plantations have been working on the problem independently and this, together with the almost unlimited variety of conditions, accounts for the lack of uniformity in results—the wide range of implements found in use. Our present need is to average these results, so to speak, with the hope of arriving at a correct answer to some of our individual difficulties.

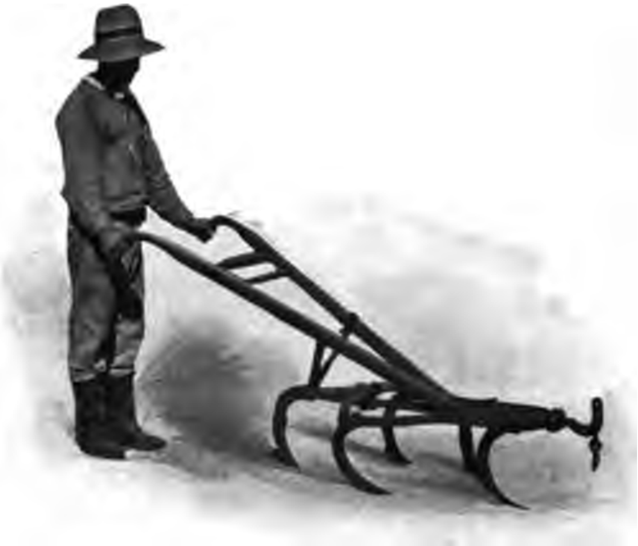

Fig. 1. Light cultivator. (*Planet, Jr.*).

CULTIVATORS.

Of the many forms of cultivators found in use, the two most popular ones are those which are commonly known in these islands as the *Planet Jr.* and the *Horner.*

The most familiar type of the *Planet Jr.** is the light five-pronged device shown in Fig. 1. There are, however, numerous modifications of this form, many of which are built in the plantation shops to suit special work. The light points, as shown, are frequently replaced by durable prongs which can resist a vast amount of wear. These vary in size and shape within rather liberal limits.

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* As used colloquially this term is a misnomer. In reality "Planet Jr." is the trade name of a line of implements. Locally it designates a particular form of implement regardless of the fact that several manufacturers supply this form to the trade. There is also some confusion regarding the term "Horner," so that the illustrations are really a more reliable guide.

Though some manufacturers provide an implement of the sort that may be neatly adjusted by levers to varying widths of row, many of the plantations prefer the stronger device which lacks this feature.

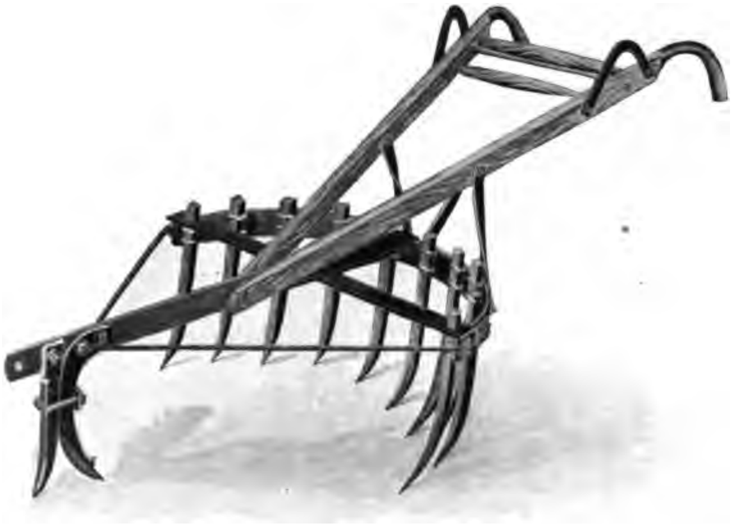

Fig. 2. Cultivator. (*Horner*).

The *Horner* cultivator is shown in Fig. 2. In many instances it is preferred to the *Planet Jr.* in that it rakes the weeds into piles. As it passes along the row it is occasionally lifted by the teamster in a manner indicated in Fig. 3. It thus loses hold of the accumulated material and proceeds to collect a new lot. This feature commends it in contending with *honohono.***

It would be needless to discuss the comparative merits of the two implements for their purpose, strictly speaking, is not identical. The *Planet Jr.*, which is much the lighter implement of the two, is ideally suited to cases in which light and frequent cultivations are practiced between the rows of cane.

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* * ***Commelina nudiflora.***

Cultivation when practiced to perfection should prevent the growth of grass and weeds. But when the too familiar exigencies demand that cultivation be not so much a preventive measure as a heroic effort to eradicate a mass of foreign growth, then the lighter implement must give way to a heavier one well designed to the purpose. In such cases the *Horner* implement has been found to do effective work.

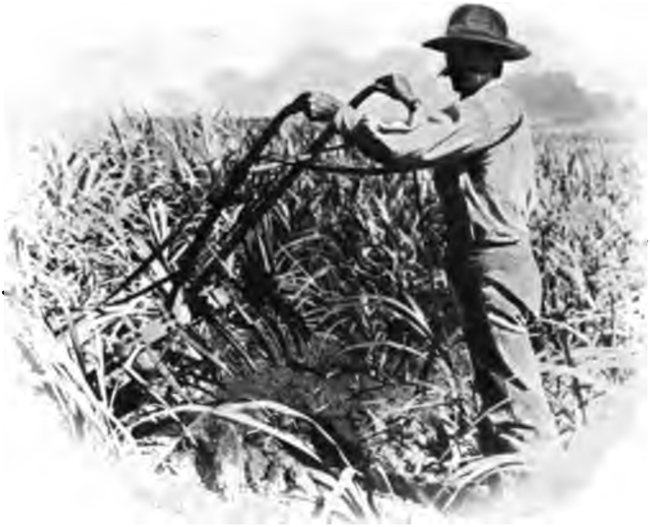

Fig. 3. The *Horner* cultivator in operation.

There is a modification of this implement known as the *Horner angle cultivator.* It is constructed with the tines to one side of the line of draft, with the idea of enabling it to be used on the side of the furrow, close into the cane. It is shown in Fig. 4.

The same implement somewhat improved is given in Fig. 5. The improved feature is the attachment which, acting as a runner, enables the implement to be held on the side of the furrow to better advantage. This idea of designing implements that will operate close to the cane appears to deserve the fullest consideration. The centers between the rows offer no great difficulty where implement work is concerned. Approaching the cane on either side the problem becomes more complex and more hand hoeing is required. Such grass or weeds as find hold along the row within the stools of cane are quite naturally the most expensive to remove since implement work is of little avail at this point. There is one implement, however, which is of great service in cultivating the sides of the hilled furrow. It can be made to operate extremely close to the cane itself and by throwing dirt within the cane and hilling a little higher each time the implement is passed, it can do more toward reducing the hand hoeing than one would think without giving it a thorough trial under conditions to which it is suited. As to what fields are suited to this implement, the *Disc Cultivator* (Figs. 6 and 7), it is rather hard to say—the more level and less rocky the better, perhaps—but a few implements of this type now doing service in these Islands have done very satisfactory work under rather adverse circumstances. Undoubtedly this implement deserves and will eventually find wider use on Hawaiian plantations. The discs need a certain amount of adjusting and this calls for a reasonable amount of intelligence on the part of the operator, but the average laborer can master its requirements in a short while when properly instructed. It

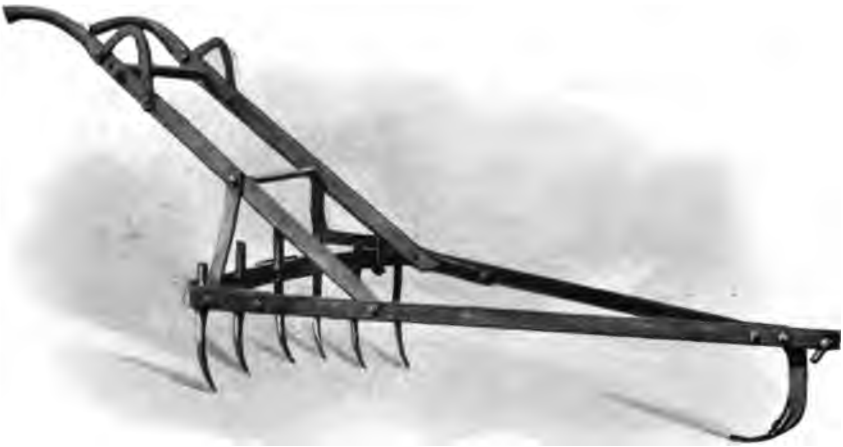

Fig. 4. The Horner angle cultivator.

is essentially a machine for hilled cane and finds no place where the cane is in the furrow. Its disc gangs should be pitched at such an angle that it will hill the cane little by little. When handled in this manner it can by repeated operations accomplish a finished job of hilling, including most of the final touches for which hand hoes are usually called into play.

Several plantations on Hawaii use a somewhat modified form of this implement. The gangs of three discs each of the regular form are replaced by single discs. This is claimed by the plantations in question to make the implement better suited to their requirements.

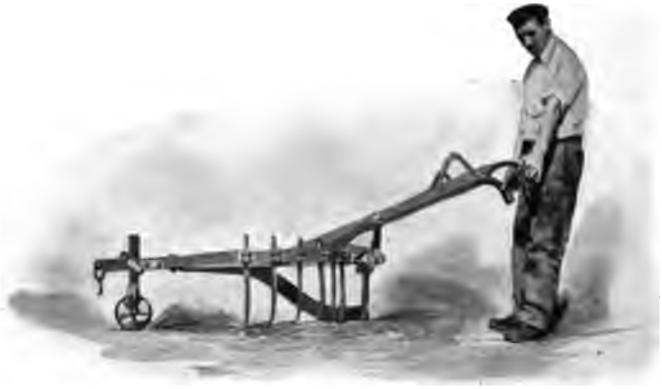

Fig. 5. A modification of the angle cultivator.

That a need is signally felt for an implement that will cultivate very close to the cane, is readily seen from the various efforts which have been made to devise such tools. Aside from those already mentioned there are several more that should be brought to attention.

One of them, that shown in Fig. 8*, consists of two frames provided with tines. These frames are loosely hinged and take position along the sides of the furrow.

A second device, built in the nature of a light scraper (Fig. 9†) is utilized for removing the weeds from very young cane, being operated astride the row.

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* Used at Onomea Sugar Mill.

† This implement is employed on several plantations in the Kohala District.

Still another effort to reach the weeds near young cane is embodied in the flat scrapers attached to ordinary plow frames shown in Fig. 10*. These shave the surface of the ground and it is claimed that they can be used to good advantage when skilfully handled.

In proceeding to a survey of other cultivators with more or less special features, we find represented in Fig. 11† an implement said to be suited for cultivating the hill between the furrows of a field laid off for irrigation. Growing cane in the furrow rather than on the hill presents an awkward problem at best when it comes to implements. The likelihood of throwing earth into the water furrow and filling it up is meant to be lessened by the small rake-like tines of this cultivator.

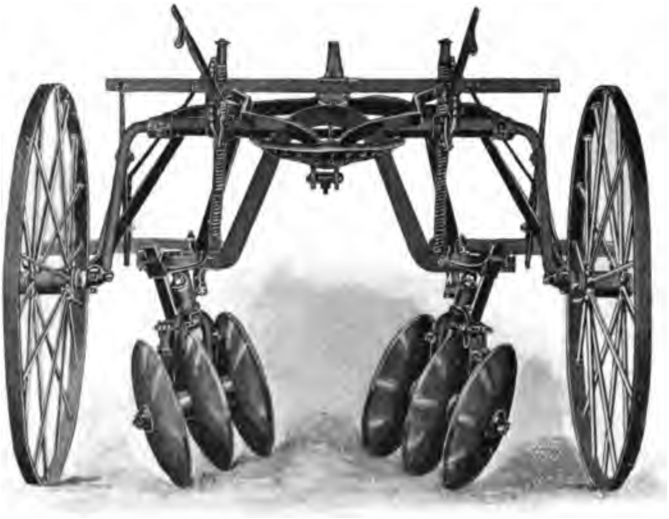

Fig. 6. The disc cultivator. (*Avery*).

In contradistinction to the *Horner* cultivator which rakes the weeds into piles, we have another tool, shown in Fig. 12, which to avoid this, is provided with tines having an outward and backward turn at their points. This causes the weeds merely to be loosened without being dragged by the implement.

*** Used at Niulii.**

† Designed and used at Halawa,

IMPLEMENTS USED IN HILLING CANE.

On the majority of the non-irrigated plantations both the plant-cane and ratoons are hilled before the cultivation is finished. In operating the cultivators some earth is naturally thrown toward the cane, and in some instances not a great deal is left to be done in the final operation of *hilling up,* as it is usually termed. In other cases the land is left fairly flat by the cultivators and suitable implements are used for throwing the earth towards the row of cane and leaving a furrow between the rows.

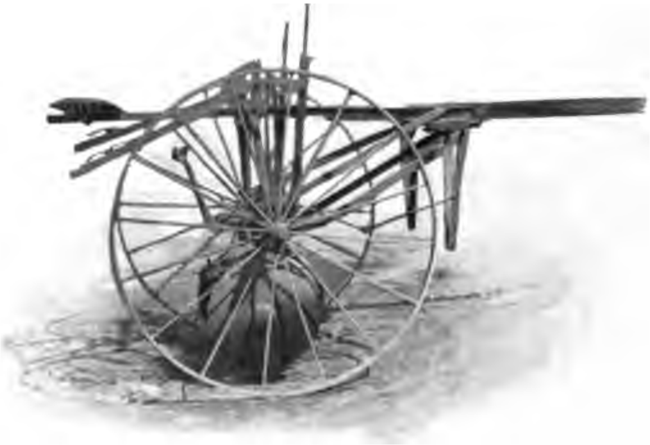

Fig. 7. The disc cultivator (side view).

The ordinary mould board plows are serviceable for this purpose and are sometimes used for the entire operation. In any event they are generally employed in the initial step of loosening the earth.

A scraper to follow the plows to throw the earth well into the cane and leave a clear furrow, is used at a number of places. These scrapers are generally of home construction and vary considerably. Sometimes they are of iron, but they frequently consist of two planks placed at an angle and supported by a frame. Two such scrapers are shown in Fig. 13 and in Fig. 13a. The ordinary celery hiller is also employed to good advantage in this capacity. (Fig. 14).

On irrigated plantations the large plows used in bedding or furrowing prior to planting are also frequently employed in the hilling of ratoons. Two such plows are shown in accompanying illustrations, Figs. 15 and 16.

A double disc arrangement (a *Benicia-Horner* implement) is widely used in hilling cane, Fig. 17. It is fitted with a small shovel to precede the discs and a subsoil plow may also be attached. Very satisfactory work has been reported in gradually hilling cane with the aid of this implement after the middle of the row has once been loosened by ordinary breaking plows. It could no doubt be used to good advantage in combination with the *sulky disc cultivator* shown on page 17. The *double disc plow* is especially adapted to throwing earth from the center of the furrow towards the side of the row. This places the earth in position to be easily reached by the disc gangs of the sulky cultivator which, in operating astride the row, pitches the loose earth into a well formed hill about the cane stalks and does away with the necessity of finishing the job with hoe gangs.

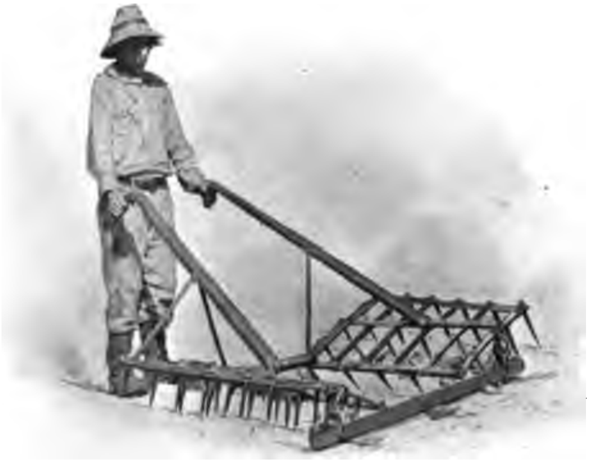

Fig. 8. Device for cultivating the furrow sides.

SPECIAL DISC IMPLEMENTS.

A modification of the *Horner double disc plow* is shown in Fig. 18. The discs are separated so that the implement may pass astride the row and *off-bar* or throw the earth from the cane. It is evident that it could not be used in this manner in cane of more than a few inches high as the shoots of cane would be broken.

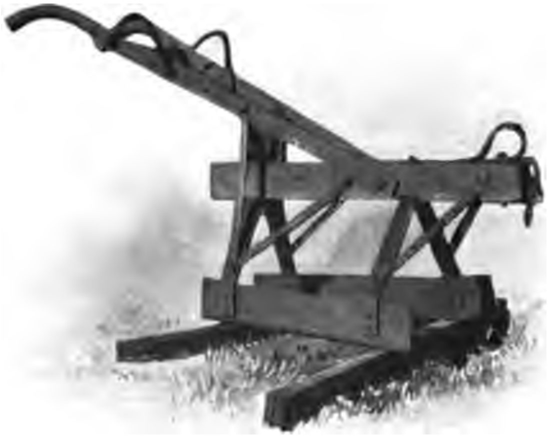

Fig. 9. Light scraper used in weeding young cane.

In Figs. 19 and 20 is an implement built somewhat on the same plan.

> "This tool," according to Mr. John T. Moir, "is adjustable, and is used for throwing away from the cane or throwing to the cane. We can either straddle the cane or straddle the middles and loosen up the soil. We put the two wheels in front to steady it while cleaning out plant cane, and the subsoilers on behind to break up the hard edges along each side of the cane. The subsoiler also tends to steady the tool at its work. By straddling the cane a great advantage is gained by having the mules hitched abreast. All parts connected with it are adjustable to the work required. We find it most serviceable in very weedy young cane, where the

hoeing would be very heavy. We use two mules to pull it and sometimes have to put them in tandem, usually when straddling the middles."

IMPLEMENTS FOR RATOONS.

Although the cultivation of ratoons when once under way does not require different implements from those ordinarily employed in plant cane, at the outset certain special implements find a place. It is the general practice on most unirrigated plantations to *off-bar* the stubbles by running a furrow close to the stubbles and plowing the earth toward the middle of the row. This is a step taken as soon as is convenient after the fields have been burned over and cleared of the debris of the previous crop. Ordinary mould board plows do this effectively.

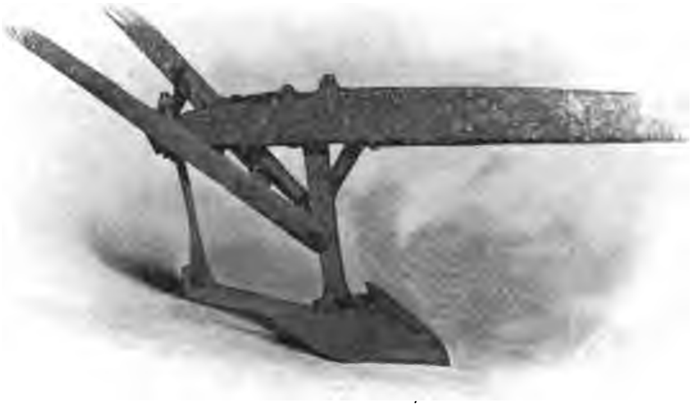

Fig. 10. Scraper plow for light weeding.

An implement shown in Fig. 21 is designed to be operated astride the stubbles. The two heavy prongs, being imbedded ten inches or more, act as sub-soil plows to loosen the earth on either side of the stubbles. The device was designed by Mr. Robt. Fricke.

A similar but smaller implement is shown in Fig. 22.

For loosening the soil to a considerable depth between the rows of stubbles or even after the young ratoons have begun to appear, we have a substantial implement having three heavy subsoiling prongs as represented in Fig. 23.

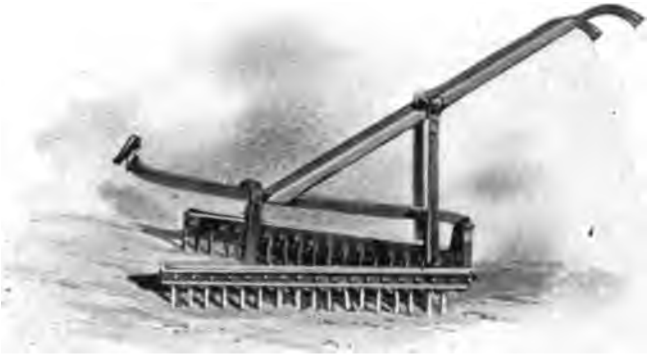

Fig. 11. Cultivator for special service.

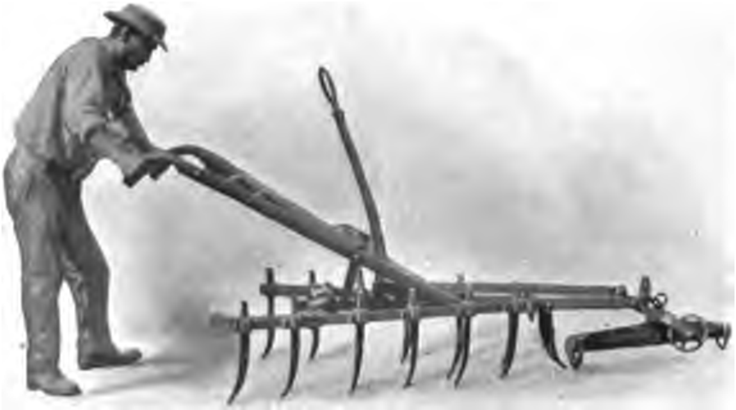

Fig. 12. Another special service cultivator.

The purpose of this implement is similar to that of the device described as the *Kilauea Hook* at the 1912 annual meeting.

This plantation-built device has three iron prongs projecting about 14 inches from a heavy wooden frame (Fig. 24). It was reported that in running these through the ratoon fields as soon after harvesting as possible, the ground is thoroughly broken to a depth of about 10 inches, with a beneficial result that is noticeable.

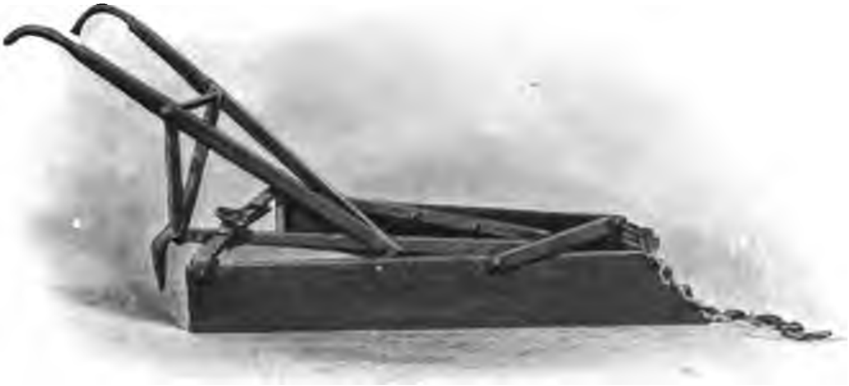

Fig. 13. Scraper used in hilling cane.

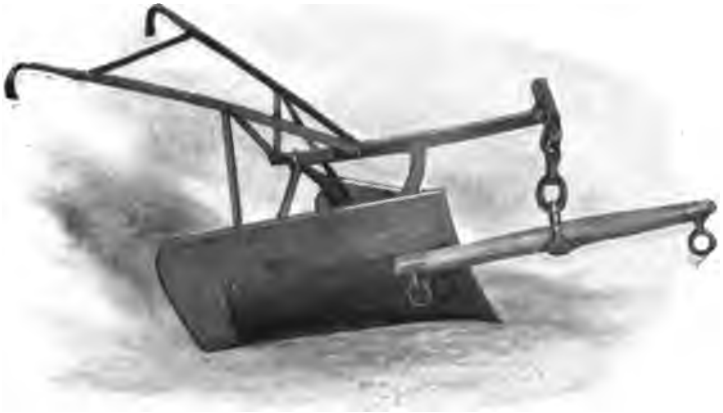

Fig. 13a. Another form of hilling scraper.

All implements of this nature deserve special attention. The deeper and more thoroughly the soil can be worked within the limit of actually uprooting the stubbles the better it would seem for the resulting ratoons. *The decreased yields in continuous ratooning is largely a matter of increased compactness of the soil.* The more that can be done to alleviate this contingency the longer, quite naturally, can the expense of replanting be profitably postponed. This is rather a self-evident idea and one that should be more fully developed in practice.

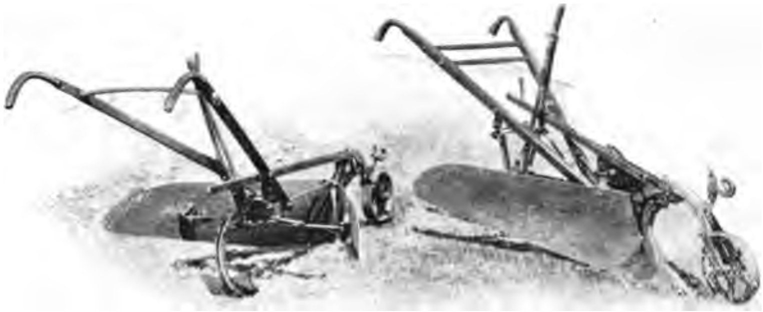

Fig. 14. The ordinary celery hiller is also employed in hilling cane.

THE PROBLEM OF CULTIVATION.

It would seem that if there is one time at which cultivation can be practiced *ad libitum* it is within that brief period which falls after harvesting and before the ratoons have developed a root system which is extensive enough to be injured by stirring the soil between the rows. In this connection it may be of interest to cite some recent observations made by Mr. W. P. Naquin and the writer which show at once, the extent of the root system of very young cane, and the danger of injuring such cane by the careless use of implements—that is, by practicing deep cultivation too late in the growing season.

By means of a clever method described in Bulletin 127 of the Kansas Experiment Station the root system of sugar cane was exhumed in such a manner as to preserve the original position of the roots. Contrary to expectation it was found that cane of less than three months' growth had developed roots which interlocked across five foot rows, and which were distributed in a very general manner throughout the fifteen inch depth of stirred soil, also which had occasionally ventured to a depth of over thirty inches—half of this into soil which gave every evidence of never having been stirred by artificial means.

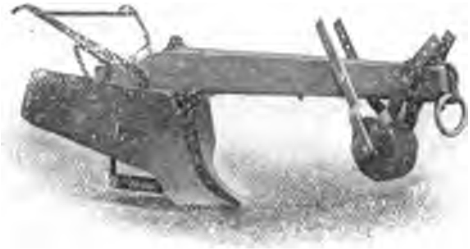

Fig. 15. Furrow plow—Lahaina type.

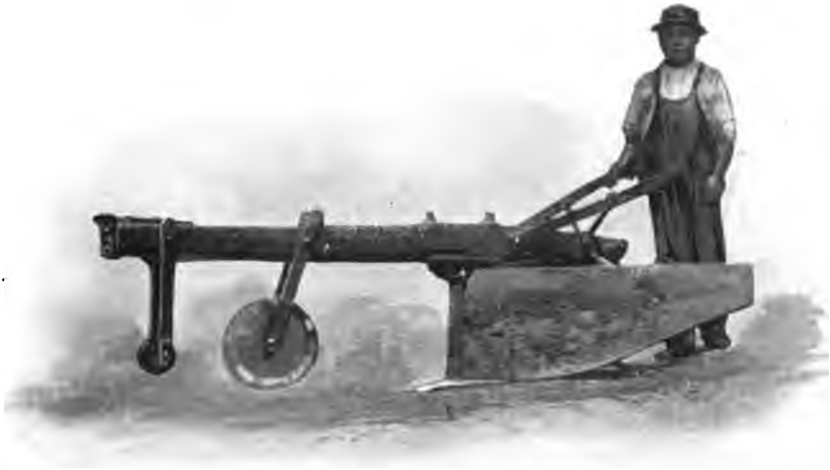

Fig. 16. Furrow plow—*Baldwin* type

It would therefore seem that cultivating implements cannot be employed to best advantage about cane without due consideration of a root growth such as is illustrated in Fig. 25. *The stirring of the surface soil about growing cane would seem* *almost inevitably to result in more or less root destruction.* When the benefits of stirring the surface soil are such as to more than compensate for this root injury—well and good. However it is important to bear in mind the fact that counteracting influences are at play, so that care may be taken that the ill effects do not offset the desired ends.

If stress is laid on this point it is because some of the most recent work in cultivation has offered rather revolutionary results.

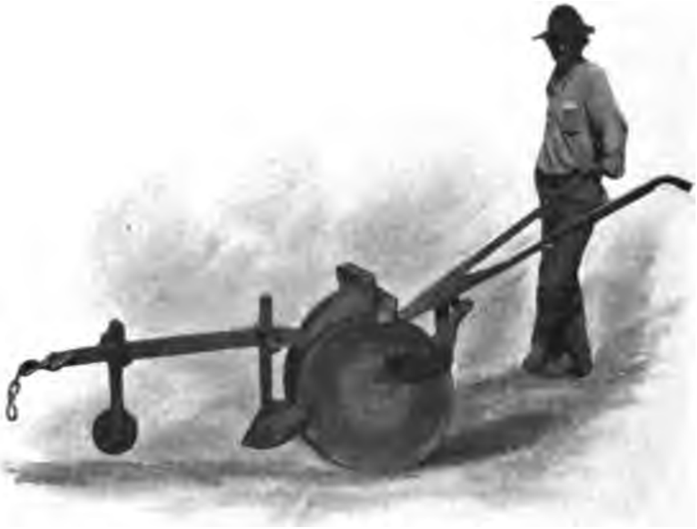

Fig. 17. The Horner double disc plow.

In the opinion of Dr. B. T. Galloway,* Asst. Secretary U. S. Dept. of Agriculture "This work seems to involve a fundamental point and sheds considerable light on the subject of tillage."

Those who are familiar with the growth of both sugar-cane and corn could hardly gainsay that the cultivation of the two crops is co-related in so far as the points at issue are concerned.

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* Letters of transmittal, Bul. 257, Bureau of Plant Industry, U. S. Department of Agriculture.

We are therefore indebted to Messrs J. S. Cates and H. P. Cox for their work entitled "The Weed Factor in the Cultivation of Corn," from which we extract the following:

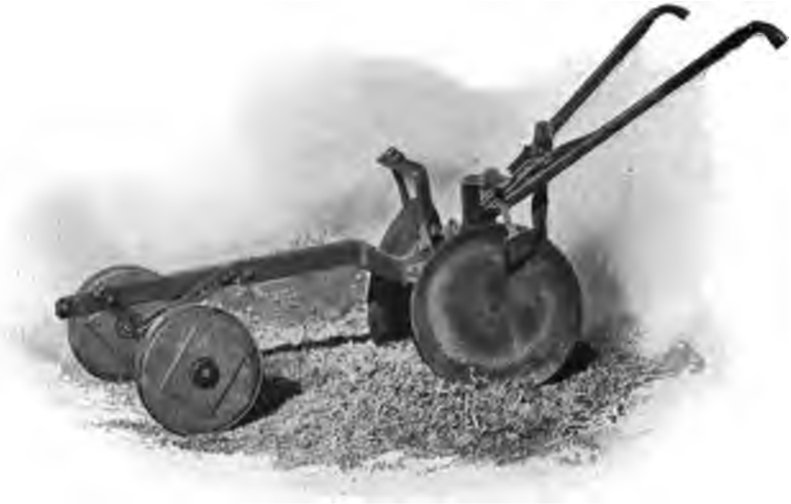

Fig. 18. A modification of the double disc plow.

"A number of tests made at several agricultural experiment stations seem to indicate that it is the weed factor that makes the cultivation of corn necessary, or, stating the proposition conversely, that cultivation is not beneficial to the corn plant except insofar as removing the weeds is concerned.

"The subject of weed control is recognized as a fundamental one in tillage philosophy. It was therefore determined to carry on, over a wide range of climatic and soil conditions, a large number of tests of the relative yields of corn produced by supposedly optimum cultivation as compared with mere weed elimination.

"The experiments were made by having two plats or sets of plats, one of which received no cultivation after planting, the weeds being kept down by a horizontal stroke of a sharp hoe at the surface of the soil, particular care being taken not to disturb the soil or to form a soil mulch; the other set of plats received the usual cultivation.

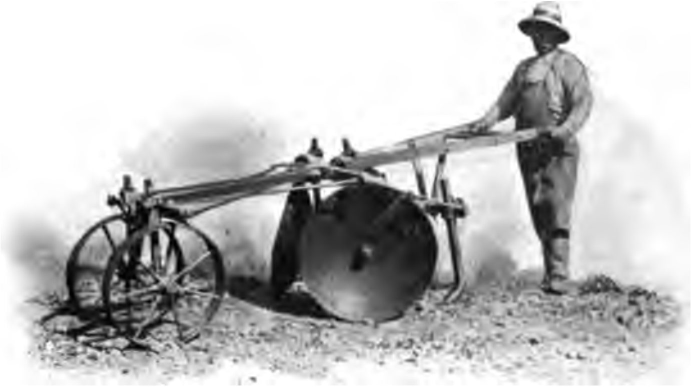

Fig. 19. Special disc cultivating device.

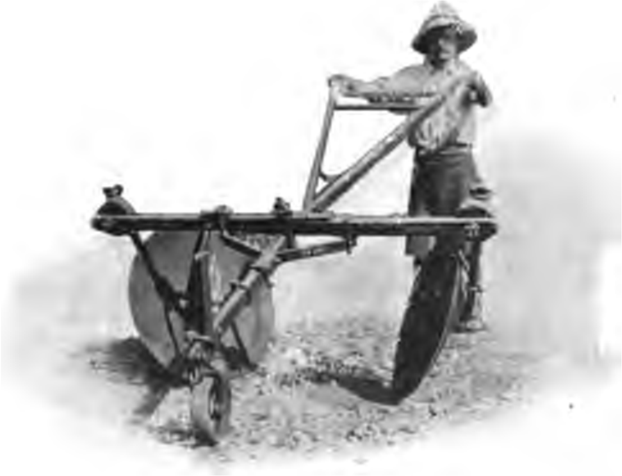

Fig. 20. Another adjustment of the implement shown in Fig. 19.

"This work was carried on by the Department of Agriculture for six years (1906 to 1911) in cooperation with several State agricultural experiment stations and with farmers, many of whom were graduates of agricultural colleges. . . . . Of the 125 experiments 124 record grain yields and 55 give fodder yields.

"A general average of all of these experiments shows that the weeded plats produced 95.1 per cent as much fodder and 99.108 per cent as much grain as the cultivated ones. If there was any difference between either set of plats in regard to thoroughness in keeping down weeds it was in favor of the cultivated plats.

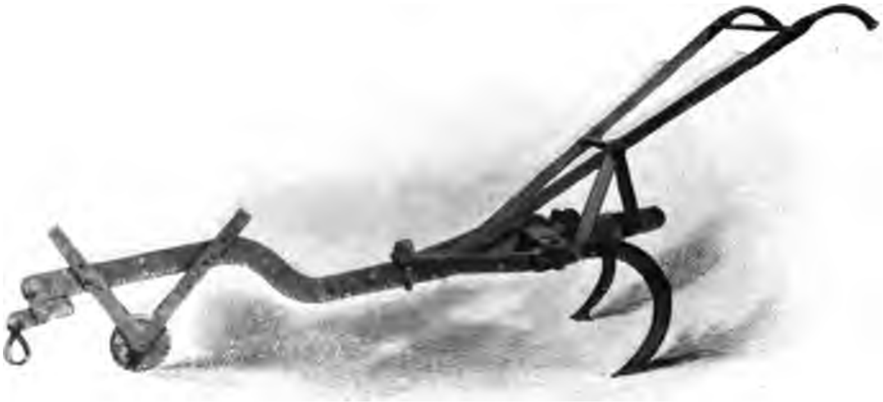

Fig. 21. A special device for ratoons.

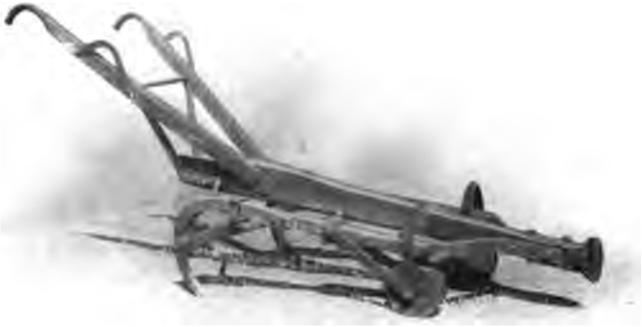

Fig. 22. Modified form of Fig. 21.

"Although it remains to be demonstrated how far this principle may be applied in any particular section, as a general average for all the regions in which this work was done it may be concluded that the proposition just stated is substantially true. If this be accepted, weed control becomes the principle object of cultivation.

"An explanation of the results obtained in these experiments is of secondary importance as compared with the interpretation we shall give them from a practical standpoint. The results as a whole come well within the limits of experimental error, showing no more difference in yield between the weeded plats and those receiving normal cultivation than might be expected between two series of 125 plats treated exactly alike.

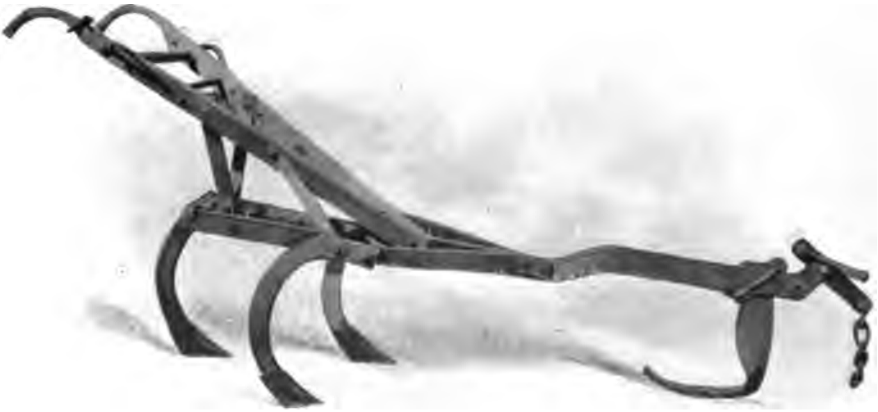

Fig. 23. Device for deep cultivation of ratoon fields.

". . . . As only a small number of experiments have been conducted in some States, it is probable that another set of tests would show considerable difference in results in many localities. It would not be advisable, therefore, to make practical suggestions for any particular locality based on the indications of these results as a whole without first making actual tests to see whether under local conditions these same principles will govern. Where these results are found to hold good, however, two entirely new fields of research are opened up, and their practical importance to the corn growers of America from a labor and money saving standpoint is not to be gainsaid. . . . .

"If it be true that weeds make the cultivation of corn necessary the problem immediately presents itself as to what farm-management methods can be pursued to eliminate or reduce to a minimum the weed pests of the farm . . .

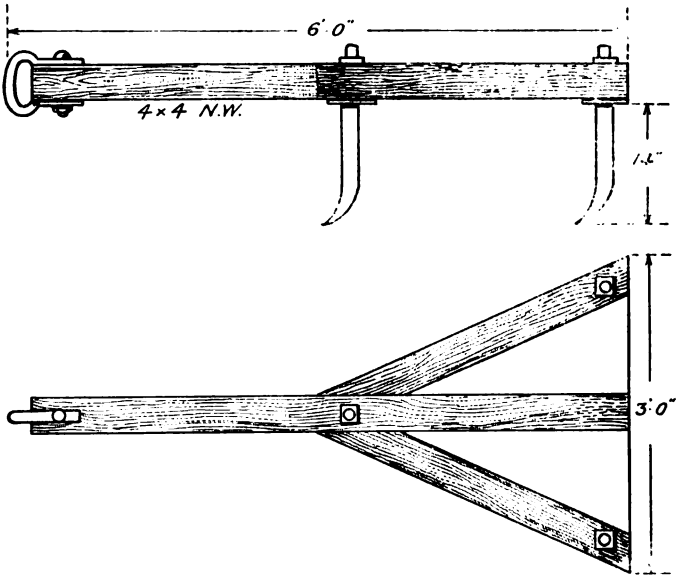

Fig. 24. The *Kilauea* hook.

"Our present implements for cultivation are designed primarily to produce a mulch and stir the ground. Weed killing is a secondary function. It is possible that newly designed implements made with special reference to weed control could accomplish this end with greatly decreased cost. The weeder will probably be considered of vastly more importance than heretofore when more data with reference to its use are available. . . .

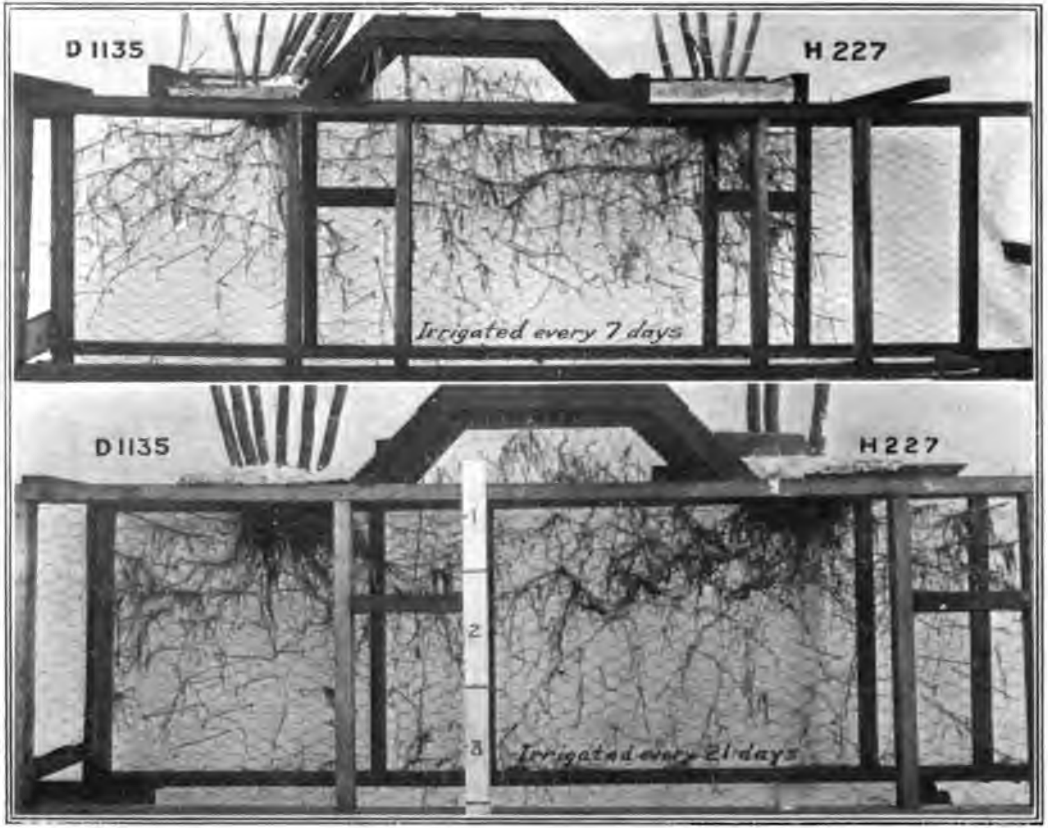

Fig. 25. The root system of sugar cane eight months old. Cultivating implements should not be used without due consideration of the root injury they may do.

> "The writers interpret the results here presented to mean that weeds are in the main the enemy which makes cultivation necessary. The exceptions should be determined by further work. Weeds can be fought from two standpoints: (1) With tillage implements specially designed to kill these pests instead of to stir the soil and make a mulch and (2) from the standpoint of rotations specially designed to overcome the weeds of the particular locality....."

WEED CONTROL BY ARSENIC.

A third method of combating weeds in cultivated fields has been developed by Mr. C. F. Eckart based upon an idea which he credits to the writer. Mr. Eckart has designed in this connection a device which was described at the last (1913) annual meeting of the Hawaiian Sugar Planters' Association as the Olaa Weed Sprayer*.

Essentially it is an apparatus permitting a spray of arsenite of soda to play upon the grass or weeds between the rows of cane without material injury to the cultivated crop.

To quote Mr. Eckart in regard to the innovation he has effected in destroying weeds:

> "The fact that in the Hilo district alone between three-quarters and one million dollars are spent annually in an everlasting fight against weeds makes any step toward economy in this branch of field work particularly important at this time, and I feel that no stone should be left unturned in definitely settling the commercial practicability of any proposed measure toward this end which carries with it the remotest degree of promise. . . . .
>
> "From numerous tests conducted by Dr. W. F. Sutherst. field chemist for the Olaa Sugar Co., it was found that a very weak solution of arsenite of soda was effective in killing the weeds if applied during dry weather. One pound of commercial white arsenic was boiled with one pound of soda ash in one gallon of water till dissolved. This stock solution was diluted with varying amounts of water and trials carried out with a hand sprayer on a

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* **Hawaiian Planters' Record, Vol. X, pp. 101-105.**

number of small cane plats. Dr. Sutherst found that a dilution of the stock to one-fortieth strength proved the most satisfactory.

"Using small sleds, carrying twenty-five gallons solution one man and one mule will take care of from three to five acres a day. From fifty to seventy-five gallons of solution are required per acre, depending upon the weediness of the field. One large water wagon, holding about six hundred gallons solution and drawn by four animals, should manage to supply about ten sleds. At this rate the average total cost per acre for labor and chemicals would be practically $0.65.

"From the results we have so far obtained in the small scale tests (15 to 20 acres) now under way I am satisfied that every precaution should be taken to prevent, as much as possible, the spray from coming in contact with the cane, and the sled is well adapted for this purpose. As it passes between the rows of cane it brushes aside any leaves or shoots which are overhanging the middles so that they do not become crushed or sprayed, the runners acting as an effective guard.

"As matters now stand it may be said that these tests are very encouraging, and if our final results convince us that this practice can safely be applied commercially the present expense for weed destruction should be reduced to less than one half. The spray kills the weeds in the middles between the cane rows and the sprayer itself as a mechanical device meets requirements. It now remains to be positively ascertained that no harm results from the application of this small amount of arsenic to the soil. Six or seven pounds of arsenic added per acre per crop to a ferruginous soil in a wet climate, would certainly not lead one to expect any harmful effects especially when it is considered that most of this element is already organically combined owing to its action on the weeds before it passes into the soil. However, it is advisable that, notwithstanding any preconceived ideas, this point should be definitely settled before the practice is put into commercial use.†

"In the commercial application of this system the following procedure would probably prove the most effective: (1) the sled to be drawn between the cane rows, following which (2) the weeds are hoed out of the cane rows and deposited in the middles, (3) the sled again passing along the middles for a second application of the solution. There would, of course, be a considerable interval between No. 1 and No. 3. In this manner instead of digging up the weeds with a hoe or cultivator and then transplanting them

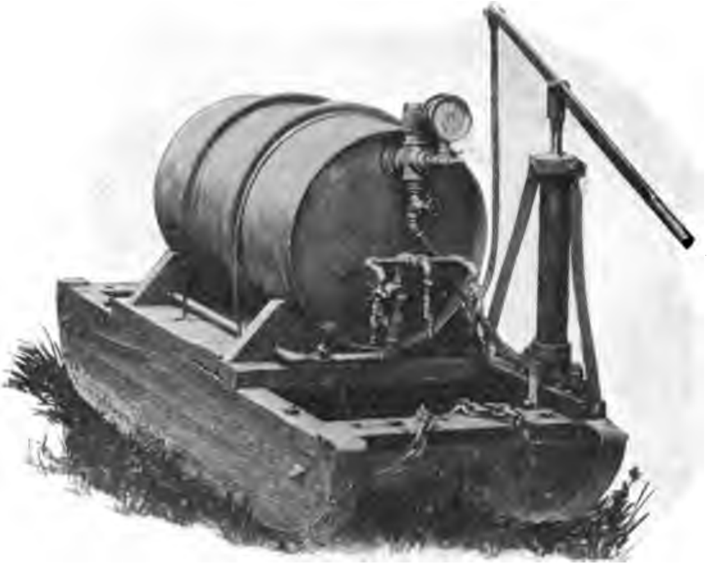

Fig. 26. ***Olaa*** **weed sprayer—1913 model.**

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† To all intents and purposes this point has since been settled. In addition to the tests at Olaa (See p. 43), we found at the Experiment Station that arsenite of soda is instantaneously fixed in non-caustic form by the iron and aluminum of the soil. This is true to such an extent that several hundred pounds arsenic per acre, the equivalent of more than fifty years of weed spraying, could be added at one dose in irrigation water without apparent injury to the growing sugar-cane.

> as is often the unavoidable practice with honohono and other weeds under Hilo conditions, most of them would be killed outright, leaves and stem.

The viewpoint of Dr. Suthrest himself in this matter may be gained from his own account of the work.

> "The question whether the weeds in the cane could be killed without damaging the cane itself is, in the writer's opinion, definitely settled. The young cane stalk is built up of the leaf sheaths, the outside of which are covered with a layer of wax; anything of a caustic nature, to a limited extent, can be sprayed on to this stalk without damage, but, of course, any spray touching the leaves damages them as much as a weed. The heart of the young cane plant, however, is not actually killed by careless spraying, even if all the leaves are, and the problem arises, can the cane recover from the slight damage due to a few leaves being destroyed? To prove the positive side of this query, a number of trials were carried out, using the above

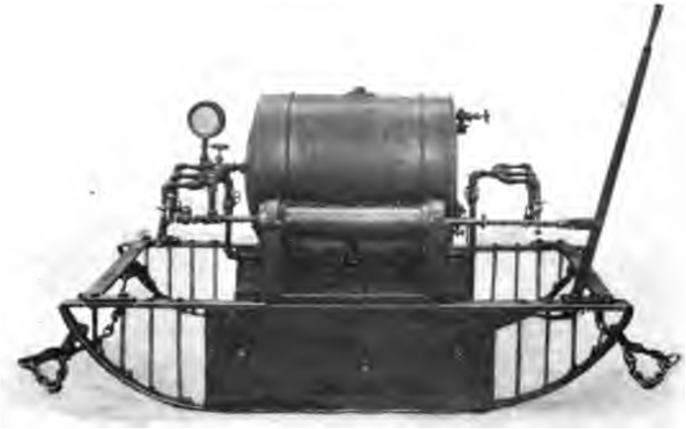

Fig. 27. The *Olaa* weed sprayer—1914 model. Note gratings to permit wider play of the arsenic spray.

named arsenite solution. The sprayer, worked by hand, fitted with a 2½-foot extension, was kept close to the ground, and the liquid injected horizontally among the cane, a time being chosen when the weeds were about 2 inches high. In every case the weeds were killed, and the cane recovered quickly from the slight check and in a few weeks was to all appearances the same as the unsprayed plots. On smooth ground a machine could be used, but for most cases it is advisable to use a hand sprayer.

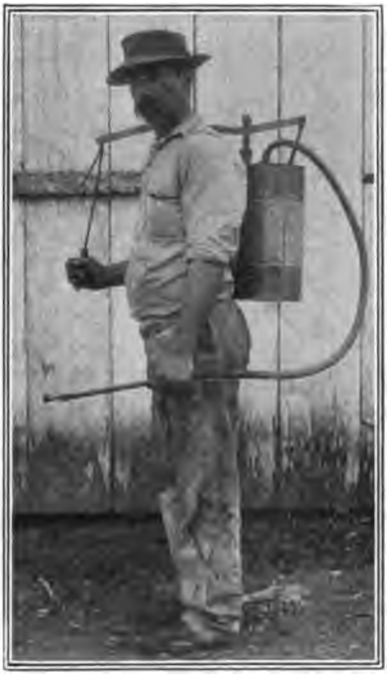

Fig. 28. The knapsack sprayer.

"The advantages of spraying over hoeing are very evident; the cost of the latter being estimated at least four times as great, since a hand sprayer can do 1½ acres per day, a machine working one cane row at a time, about 5 acres, the cost of chemicals is practically negligible, being about 10 cents per acre. It has been proved experimentally by the writer that a sprayed area remains weedless for a very much longer time than a hoed area, since by the latter method, fresh weed seeds are brought to the surface and only needed this for germination; also, in wet tropical climates, the weeds actually removed with the hoes or by hand will, in most cases, continue growing in a new location, so that, theoretically, one spraying should take the place of two or even three hoeings. Hoeing and, in fact, any surface disturbance of the soil, leads to soil washing during rain, and if done during wet weather, as is often the case, tends to puddle clay soils. It might be argued that leaving the soil thus without any hoeing or cultivation would be harmful to the cane growth, but in rainy districts, to which this article chiefly applies, no good purpose comes of these operations, as the loosened soil is immediately beaten compact or washed away. Again, the cane gets no cultivation for the last 12 or 18 months of growth, and it seems to thrive during that period as well as any other. In the Hawaiian Islands the soil is so

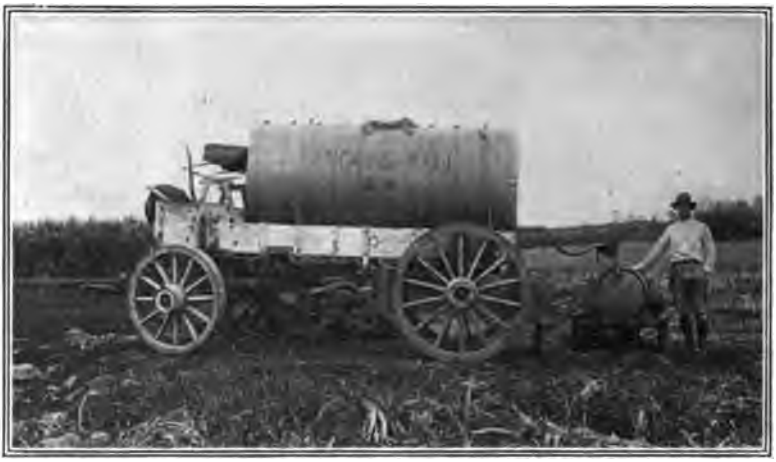

Fig. 29. The arsenic supply tank (*Olaa*).

porous that most of the rain percolates at once through the subsoil to the lava rock underneath. This brings about a natural aeration of the soil (the main object of cultivation), which is undoubtedly hindered by hoeing or cultivating soils in wet climates.

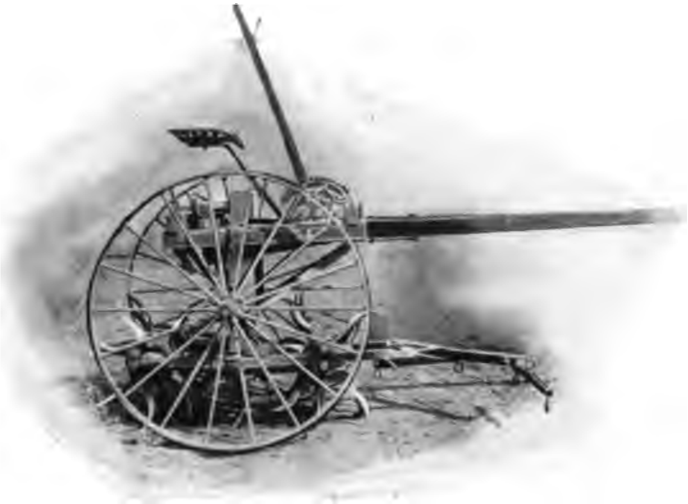

Fig. 30. The stubble digger (*Avery*).

"It must be noted finally that all spraying operations require very great care in their manipulation; during rain, of course, it must not be done, but soon after a shower, especially if the sun shines, it can be continued; rain two hours after spraying is no detriment. By observing these rules and using ordinary intelligence, spraying can save a plantation in labor from 15 to 30 dollars a year per acre."

These opinions of Mr. Eckart and Dr. Sutherst were published some months ago when this innovation in agriculture was yet, we may say, in a semi-experimental stage.*

It has since been adopted as a regular field practice throughout the lands of the Olaa Sugar Co. and it may therefore be of interest to refer to the reports of Mr. L. D. Larsen, who recently visited Mr. Eckart on behalf of the Experiment Station.

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* Hawaiian Planters' Record, Vol. X, p. 204.

"The strength of solution used at present (April, 1914) is 5 lbs. of arsenite to 100 gallons of water. The stock solution consists of:

20 lbs. arsenite.
4 to 5 lbs. of soda.
10 gals. water.

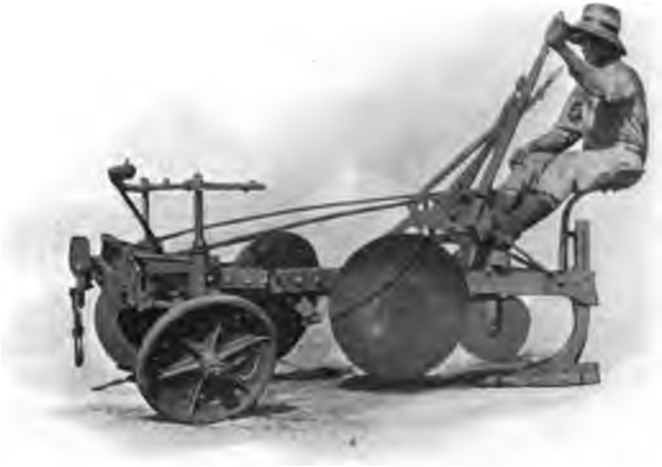

Fig. 31. Stubble breaker.

"This is boiled for 10 to 15 minutes. Fifteen gallons of this stock solution are diluted to 600 gals. in the big supply tanks. The pictures show these supply tanks as well as the feed tanks, and the sled and hand sprayer.

"When hand spraying is done a feed tank is used to carry the solution from the big supply tank on the road to the men with the hand sprayers in the fields. This feed tank consists of an oil barrel attached to a stone sled. It holds 50 gals. It is pulled by one mule and may be taken into the smaller field roads and between the cane rows. The sled sprayers consist of a 25-gallon iron tank on a 3-foot wide sled. It has three spray nozzles at each end, a pump and sometimes a pressure gauge. The nozzles may be pushed closer together or further apart, according to the

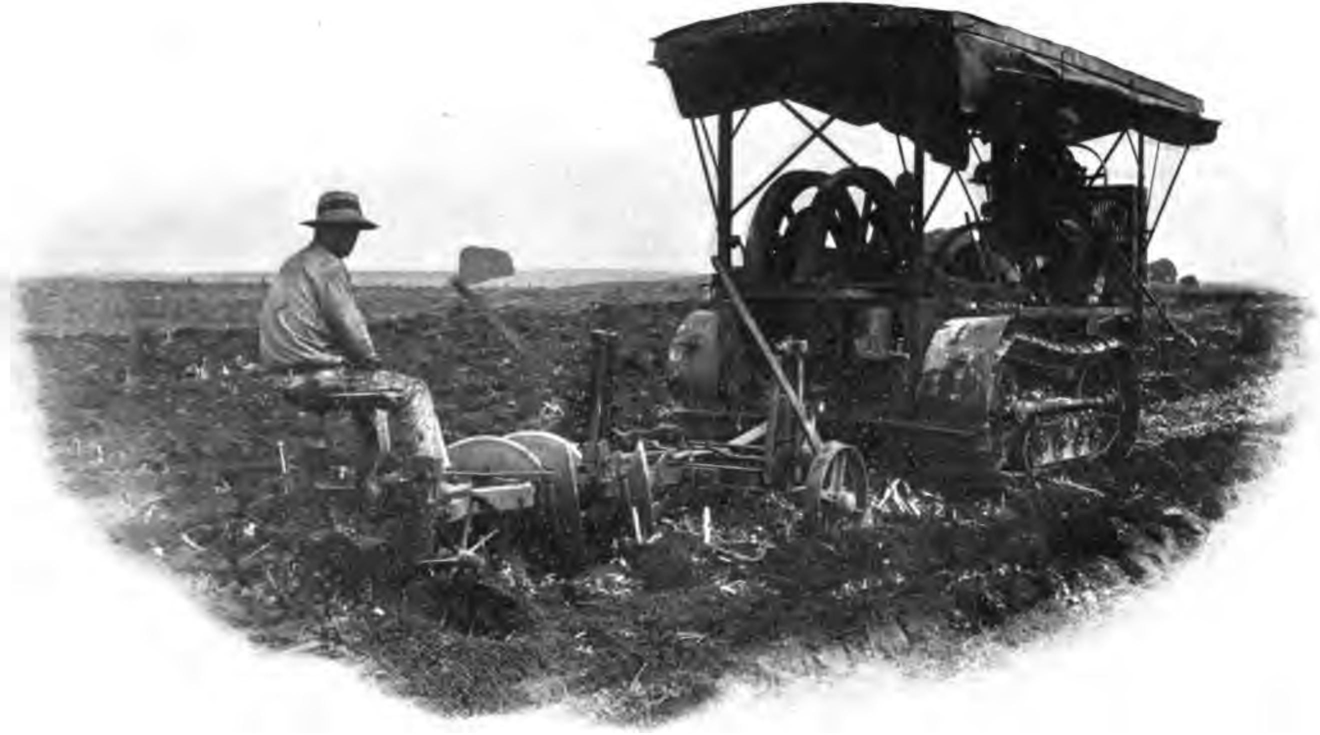

Fig. 32. Stubble breaker, (*Scott*)—hauled by a caterpillar tractor (*Holt*).

width of furrow one desires to spray. No guards are used to protect the cane and it is not considered necessary. The injury I was told is not appreciable. I did not see the sled sprayers in action. Where the hand sprayers were being used it was hard to find specimens of leaves that had been touched.

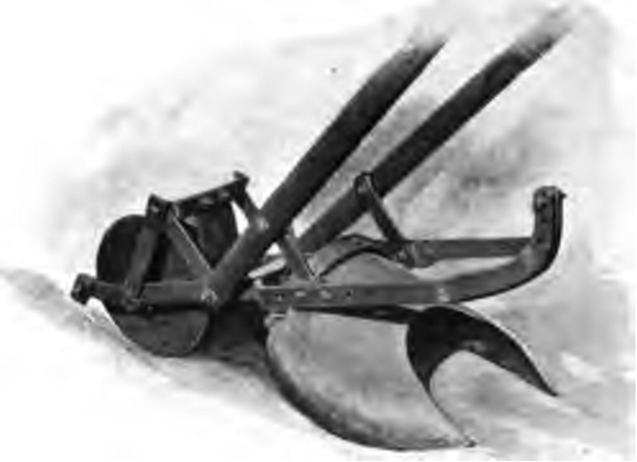

Fig. 33. A device for covering seed-cane

"It is Mr. Eckart's plan to do as much sled-spraying as possible and to follow this, after a short interval, with a light hand spraying to touch up the spots that may have been missed by the sleds. In sled-spraying, when the weeds are light, the spraying is done from one end of the tank only (with 3 nozzles). When the weeds are plentiful spraying is done from both ends (with all 6 nozzles).*

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* The nozzle used is a Deming-Vermorel. It costs 60 cents at Olaa. The knapsack sprayers cost $5.00 f. o. b. San Francisco. They were bought from the Pacific Hardware & Steel Co., San Francisco. The arsenite comes to 5 cents a pound at Olaa, and the soda at 3½ cents. In mixing the solution they have had best success by dissolving the soda first and after this has come to a boil, adding the arsenite gradually.

"The cost of spraying at present is from 50 cents to $1.00 for sled-spraying, and from $1.00 to $1.25 for hand spraying. The maximum amount of work for the sleds is 5 acres per day. The maximum for hand spraying is a little over one acre. From two to four applications are required per crop, depending largely on the weather conditions. The weather during the past season has been unusually favorable to successful spraying.

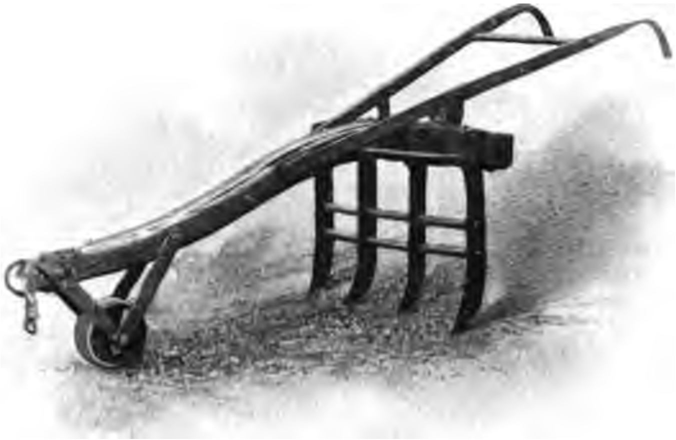

Fig. 34. A trash rake.

"An interesting experiment is being conducted in one of the fields to test the accumulative effect of the arsenic upon the cane. Ten rows of cane, each a hundred feet long, are included in this experiment. Arsenic is being applied to the soil at the rate of 5 lbs. per acre each week. The experiment has been running since October 25 and 140 lbs. of arsenic have been applied already. As yet no injurious effects whatever are noticeable.

"According to Mr. Eckart they have dispensed with fully half of their cultivating by the use of this arsenite and have reduced the amount of hoeing very materially. The spraying goes much closer to the cane than the cultivators can, and makes the hoeing in the cane rows cheaper. He says that they can probably do away with all of their cultivation from *off-barring* to small plowing before hilling up. If this can be done, and I see no reason why it cannot, the saving would be very much greater. He is also planning to spray along the roadways to keep the weed seeds from maturing and infecting the fields."

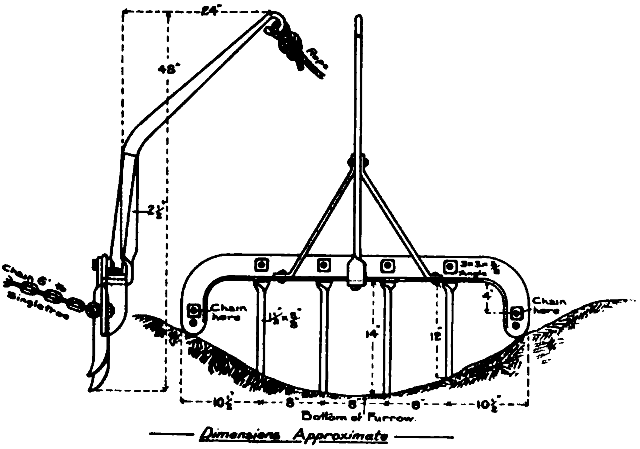

Fig. 35. Another trash rake.

MISCELLANEOUS DEVICES.

The Stubble-Digger.

The stubble-digger, Fig. 30, an implement widely used in Louisiana, is found on several plantations in these Islands. As it is run along the row the spikes puncture the earth in and about the stubbles, loosening them to a certain extent and thus offering the forthcoming ratoons a greater freedom for root development. Though we have no definite information as to its benefits in these islands several managers endorse its use.

At a few plantations in the Hilo district good results are reported from running a heavy spiked harrow over the stubbles before off-barring. In this operation the stools are torn to some extent, but where the stubbles are tough and strongly rooted decided benefit is said to result.

Stubble Breakers.

On several plantations near Hilo the stubbles of the Yellow Caledonia cane are so large and difficult to plow out, that special implements are required for breaking them. One of these devices is shown in Fig. 31. It is fitted with two large discs which split the stubbles and throw them out with the aid of the subsoil plow in the rear. The implement is of very heavy draft and requires 8 mules.

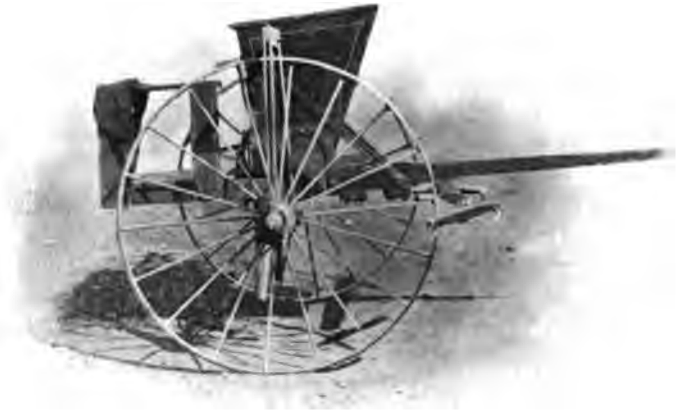

Fig. 36. Fertilizer distributor (*Avery*).

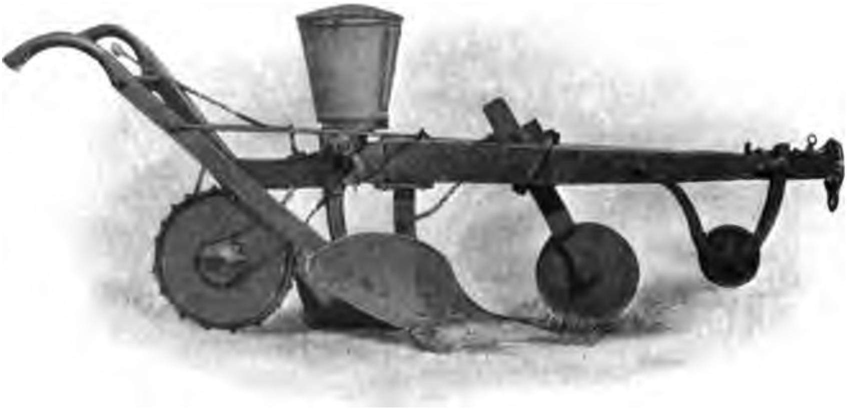

Fig. 37. A fertilizing plow (*Ogg*).

Another form of stubble breaker is illustrated in Fig. 32 being hauled by a tractor engine. It is constructed on somewhat the same principle except that there are two discs on either side.

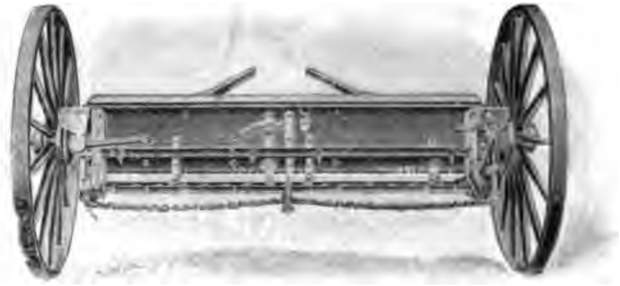

Fig. 38. Lime distributor (*Westphalia*).

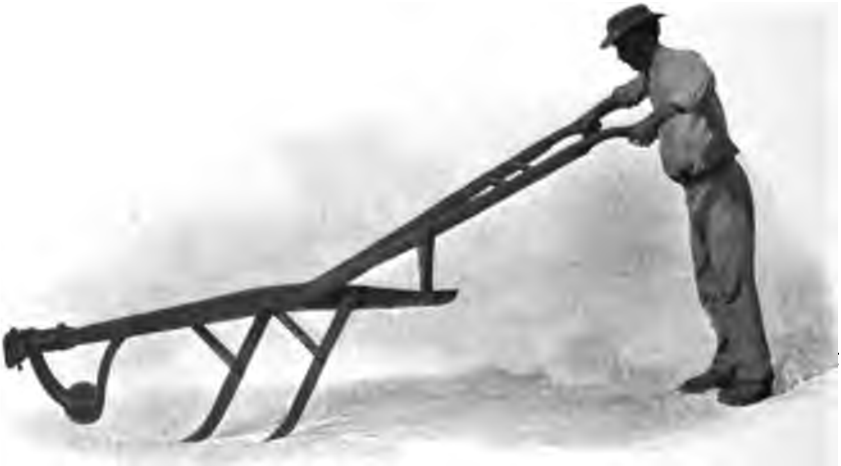

Fig. 39. A light plow for loosening the seed-bed or covering fertlizer.

Seed-Cane Coverer.

A device which may be substituted for hoes in covering seed-cane is shown in Fig. 33. It is an invention of Mr. Robert Hall and has been used to a considerable extent at Niulii. It is said to lighten the expense of planting.

Trash-Rakes.

The work of cultivating is often impeded by the presence along the cane row of loose trash and debris from the previous crop. The device shown in Fig. 34 may be used to clear the way of this material, thus facilitating subsequent work with implements.

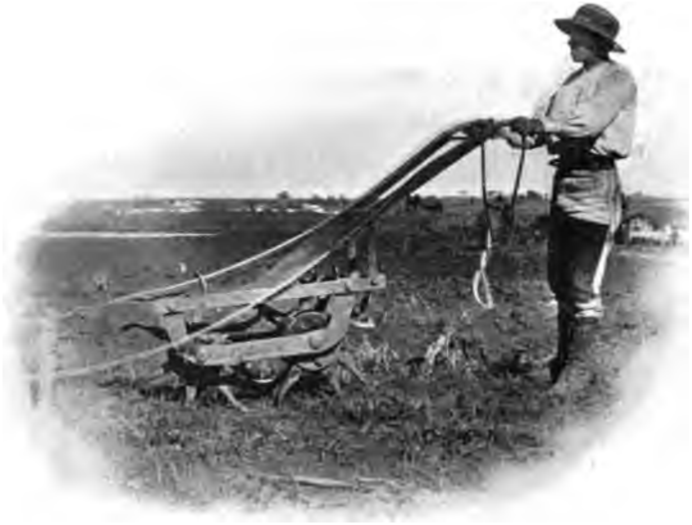

Fig. 40. A spur wheeled device for preparing the seed-bed.

Still another form of trash-rake is shown in Fig. 35. It is designed more especially for clearing trash from a field which has been imperfectly burned off as may frequently occur when the weather is unfavorable. The accompanying illustration, Fig. 35, is taken from the Planters' Record, from which we quote the following description of the use of the rake:

"A draft animal ridden by the driver is hitched with the single-tree about six feet ahead of the rake. A rope is attached to the upper end of the arm and is manipulated by another operator who may at intervals exchange places with the driver. The rear operator keeps the rake in an upright position until it is desired to dump the load. At this point he simply releases tension on the rope, the rake rides over the trash it has accumulated and is again drawn in position for the next load. It is

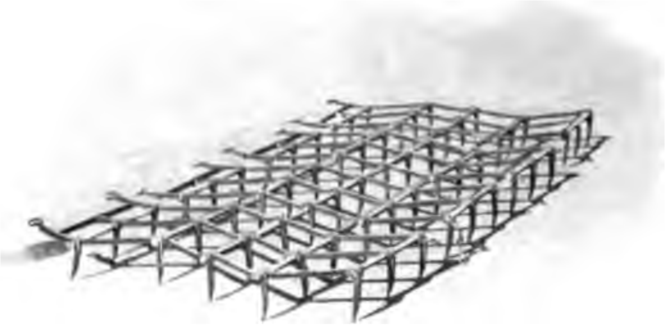

Fig. 41. Loose link harrow.

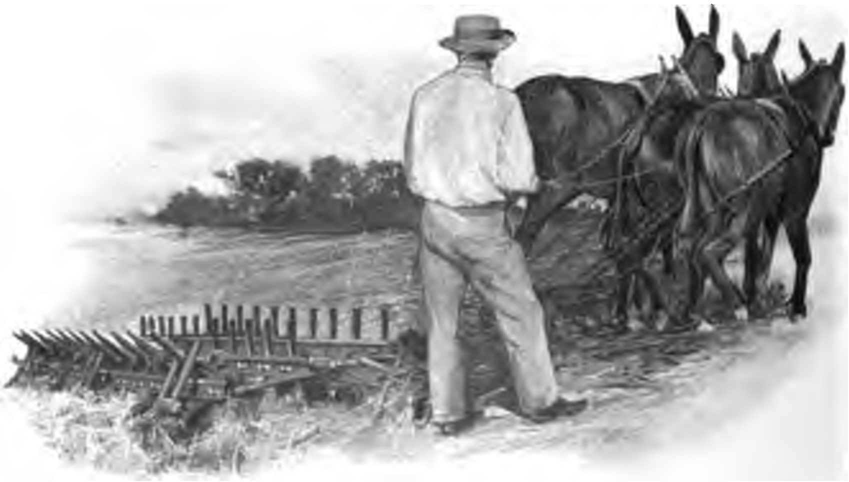

Fig. 42. Rigid link harrow.

a continuous process, there being ordinarily no necessity to stop. With experienced labor one operator is sufficient. Under favorable conditions this rake can clean up the trash from five or six acres a day."

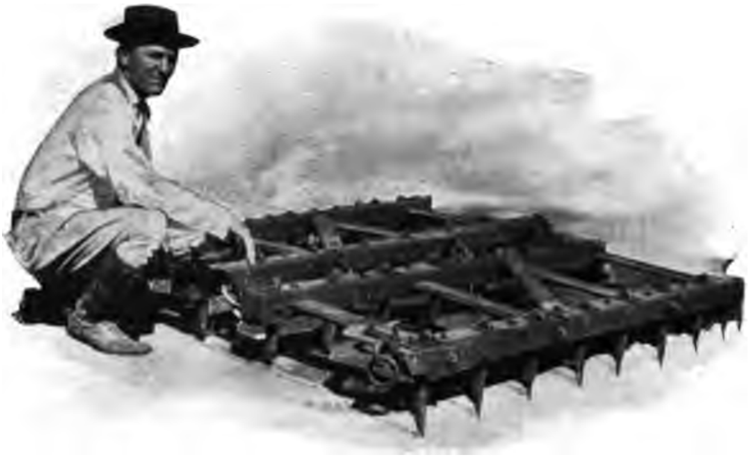

Fig. 43. Heavy harrow for rocky land.

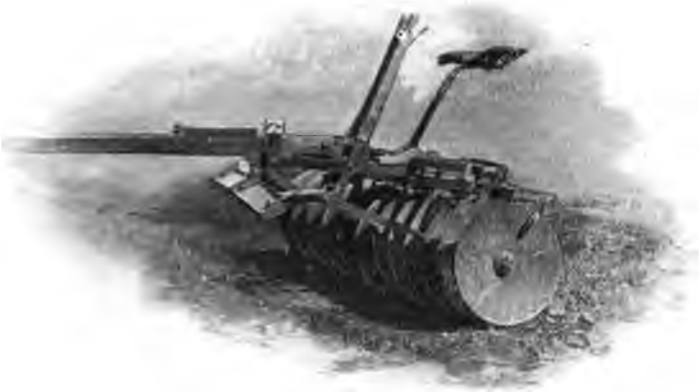

Fig. 44. The disc harrow.

The device is an invention of Mr. H. B. Penhallow.

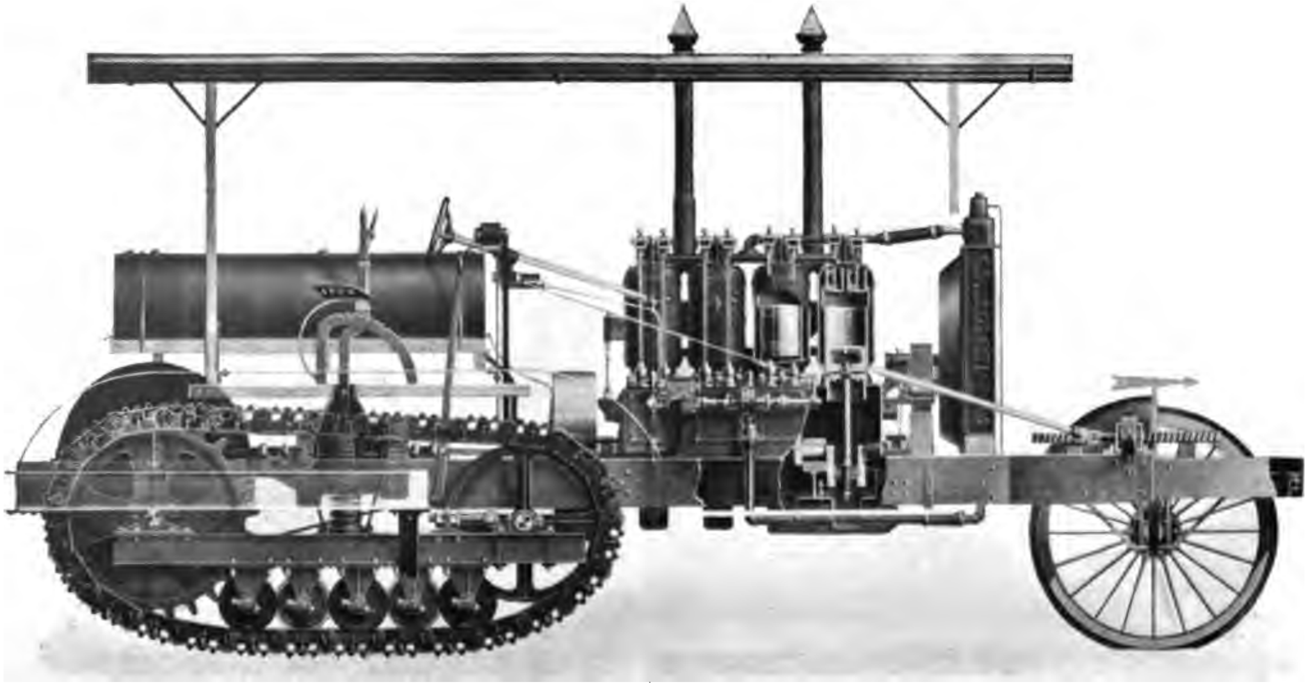

Fig. 45. Transparent view showing detailed construction of a track-laying tractor.

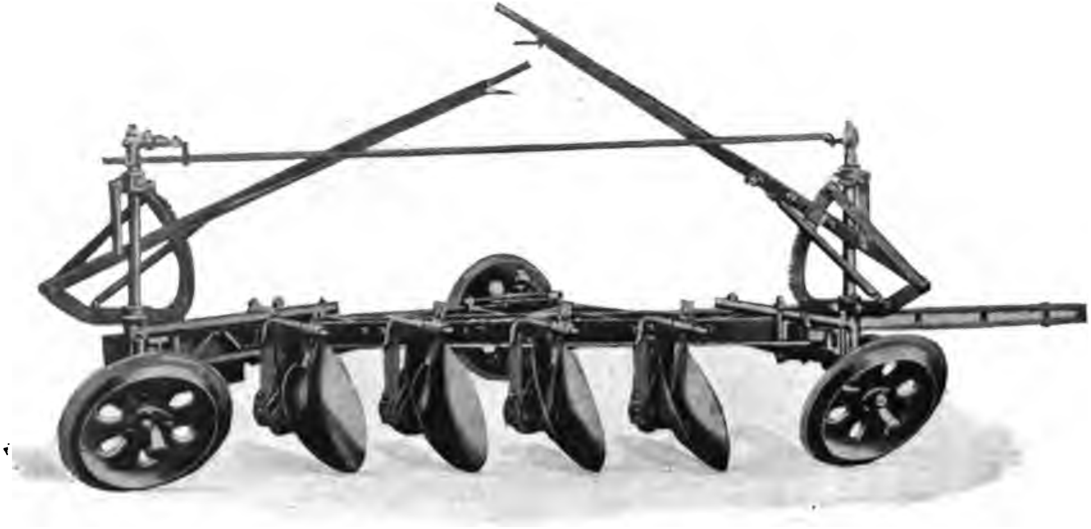

Fig. 46. The engine disc plow (*Deere*).

Seed-Bed Preparers.

It is customary in some districts to loosen the earth in the furrow before planting. A light two-pronged plow for this work is pictured in Fig. 39. It also finds service for scratching a light furrow in covering fertilizers.

A second device of this character is shown in Fig. 40. It is provided with rotary prongs.

FERTILIZING MACHINES.

The use of machines for the distribution of fertilizers has not as yet gained a wide popularity in these islands, but certain plantations have reported a decided preference for the machines as against hand distribution. An actual monetary gain is claimed in some instances in connection with certain other advantages in the way of a more even distribution of the fertilizing material, and the smaller number of laborers required in the work.

The *Avery* type is shown in Fig. 36. One manager, Mr. Broadbent, reports that these machines are doing good work after six years of service. He considers five acres per day as a fair average for each machine in applying fertilizer at the rate of 1000 pounds per acre. "On fairly level fields with long furrows more than five acres are covered," he states, "while on uneven fields, where furrows are crooked and short, not so much is accomplished."

A substantial and simply constructed machine having high wheels is preferable to one which lacks these features. The higher wheels enable larger cane to be fertilized, as a machine which sets close to the ground is more apt to break the cane.

We have also seen a distributor of home construction provided at the rear with a scarifying device for covering the fertilizer as it is applied. We have at hand no report as to the economy of thus handling the two operations in unison.

A combination of a plow and fertilizer distributor is shown in Fig. 37. Obviously this finds a field of usefulness only when plowing and fertilizing can be advantageously performed at the same time. This is the case on a few plantations when young ratoons are *furrow plowed* or *off-barred*. The device is an invention of Mr. James Ogg and is reported to work successfully at the Hawaiian Agricultural Co.

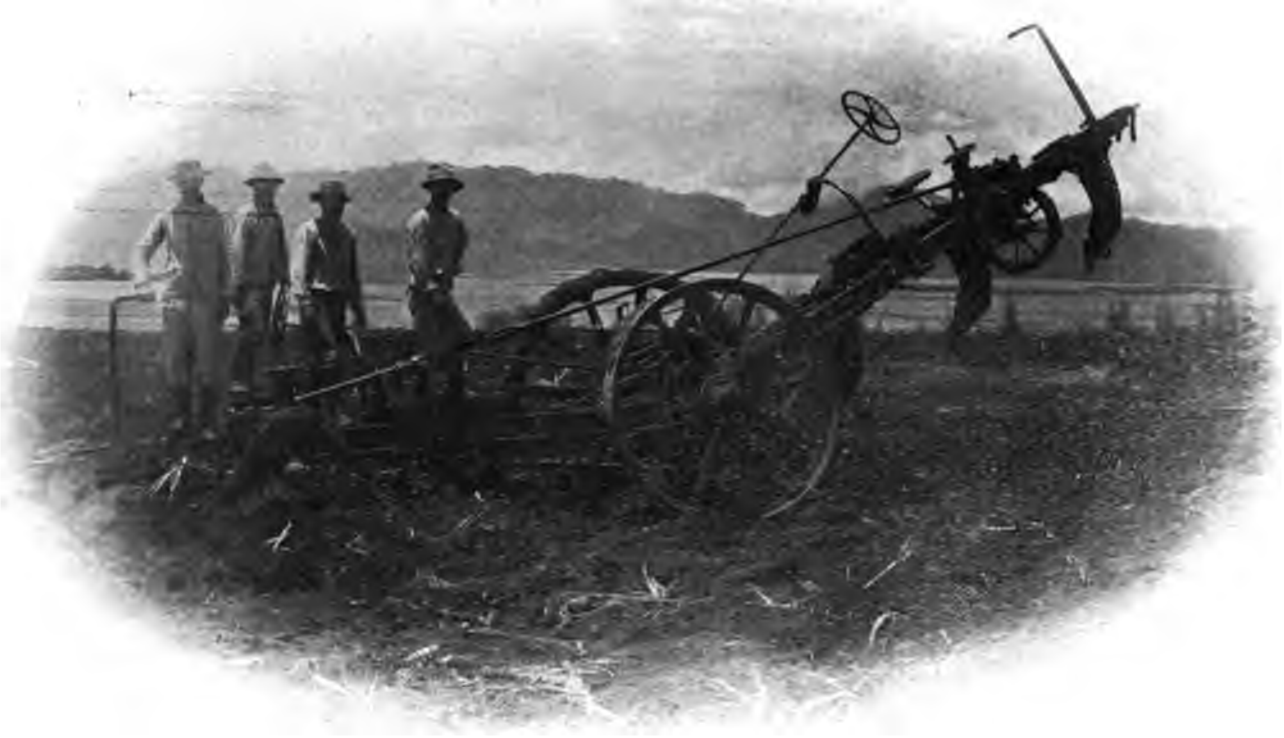

Fig. 47. The three gang plow (*Fowler steam tackles*).

For the distribution of lime an ordinary fertilizer distributor may be employed or a device of special construction is commonly resorted to, such as the Westphalia type as illustrated herewith (Fig. 38). Frequently machines of this type must be strengthened by adding braces or the conditions of the average sugar plantation will prove too severe.

The ordinary manure spreader constructed along the lines of the ordinary farm wagon has in general proved unsuited to the conditions of our plantations and there appears to be a field for a more heavily constructed spreader than is commonly marketed —one better prepared to encounter the deep furrows and ditches which are to be met with.

HARROWS.

The variety of harrows found in use is so great that we have only attempted to illustrate the various types.

In Fig. 41 is one that is very popular. It consists of a series of links, each provided with a tine or prong. The loose-jointed links permit the implement to ride over uneven surfaces and cause it, when clogged with grass or debris, to buckle sufficiently to free itself.

A second widely used form consists of a number of tines attached to a rigid frame. In many instances a harrow of this nature is preferable to the one just described. There are many variations of this form.

The harrow shown in Fig. 42 is in use in the Kona district. It was originated by Mr. E. E. Conant. It embraces a combination of the desirable points of each of those just previously described. It consists of a series of hinged frames. These frames give it rigidity, while the hinged joints permit it to buckle sufficiently to free itself of grass or debris.

In Fig. 43 is a harrow used in the Olaa district. It is especially constructed for rocky lands, its chief features being weight and durability. The two sections as shown are of metal and are said to weigh 640 pounds.

On a few plantations the disc harrow (Fig. 44) has been tried and is reported to give most satisfactory results. This is an implement that should particularly appeal to those who are becoming interested in green manuring crops. When passed across such a crop, the cutting action of the disc reduces the growing material to a state well suited to be turned under by plows.

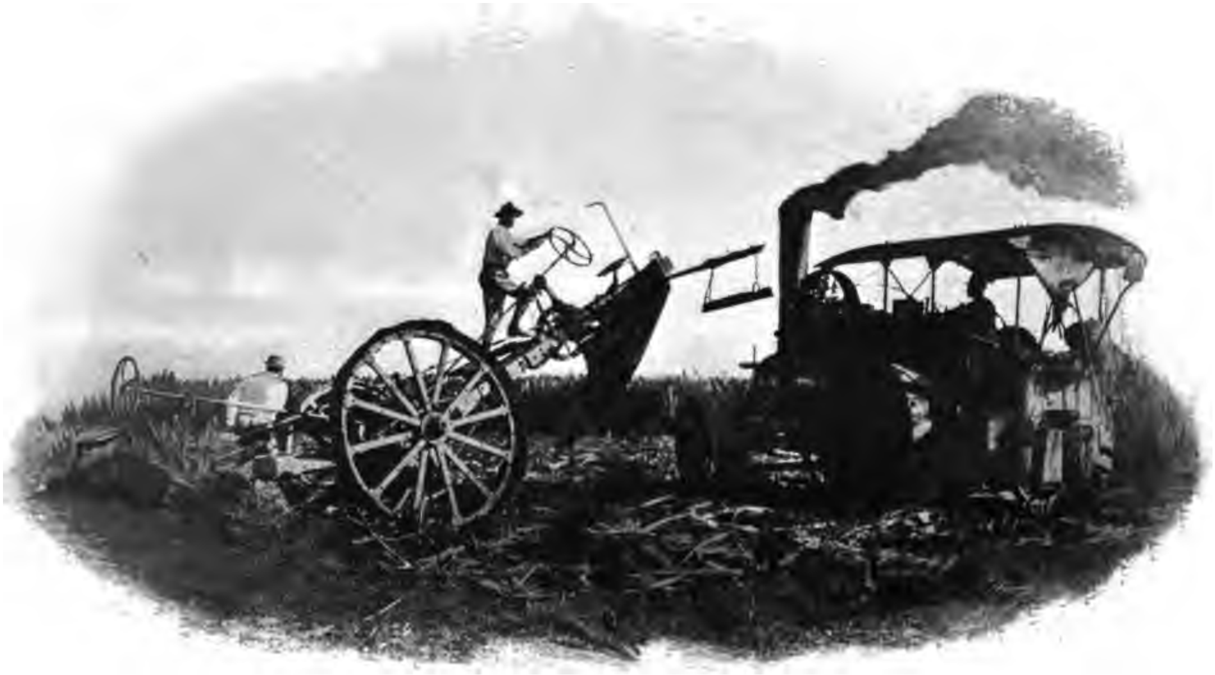

Fig. 48. Single bottom steam plow (*Fowler*).

TRACTOR PLOWING.

It is not unlikely that gasoline tractor plowing will eventually encroach to some extent on both the animal plowing and the steam plowing of these Islands. In fact, an initial inroad has already been made. The so-called *caterpillar* or *track-laying-tractor* is so well suited to traveling over rough fields that it undoubtedly deserves consideration in studying the possible economies in land breaking. Two types of such tractors are shown in Fig. 45 and in Fig. 32.

A leading point is to secure a suitable plow to trail behind the tractor, and from all accounts the pioneer tractor-plowing in Hawaii has been somewhat handicapped on this score.

Perhaps the most efficient plow for this purpose which has met our observation is the *engine disc plow* shown in Fig. 46. The discs on this particular implement are twenty-six inches in diameter, there is ample clearance between the discs, and there are many points about it which bespeak skill in designing.

This plow, insofar as we have yet heard, has not found its way to any of the sugar plantations, but it has done very excellent work in breaking new land in the pineapple areas of Oahu.

STEAM PLOWING BY CABLE.

The excellent yields of these Islands are probably due as much to deep plowing as to any other one factor. The greater part of this deep tilling is done by the *John Fowler steam plowing outfits.* In fact, as was pointed out by Mr. Geo. F. Renton (1911 annual meeting) "it is certainly a compliment to the manufacturers" that "the steam plows in use in Hawaii have all been manufactured by one firm." Mr. Renton proceeded to estimate that "Taking it all around, there is invested in this Territory in plowing engines, cables, plows and accessories, about a million dollars."

For breaking land the three gang outfits shown in Fig. 47 are ordinarily employed. Possibly the deepest plowing in these Islands, if not in the entire world, is accomplished by the single furrow plow shown in Fig. 48.

There are two modifications of these ordinary mould board forms. In the first of these (Fig. 49) the mould boards which turn the soil as they break it, are replaced by heavy tines which act as a knife and merely break the land, without upturning it.

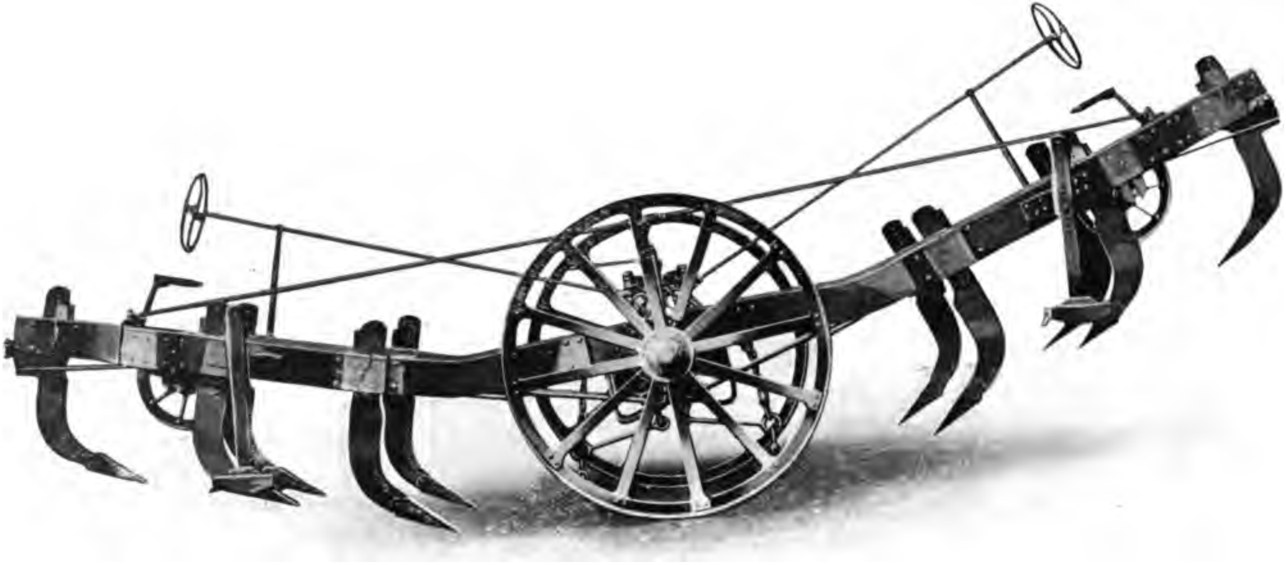

Fig. 49. The knife plow (*Fowler steam tackles*).

This arrangement gives valuable service where the subsoil is of such a nature that it would be inadvisable to effect its admixture with the surface soil. By breaking it with the so-called *knives* this soil is gradually aerated and made of service to the crop. A number of managers have reported excellent results from the use of this implement where the surface soil is comparatively shallow. The second modification consists of a

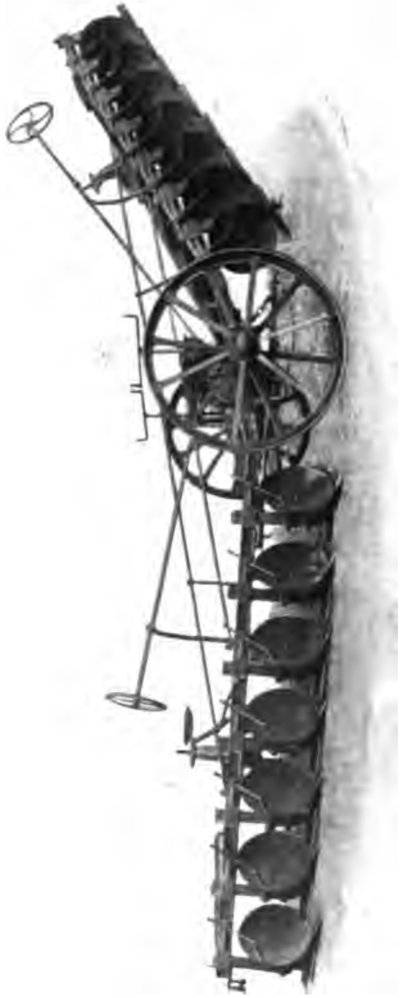

Fig. 50. Disc plow (*Fowler steam tackles*).

substitution of revolving discs for the mould board plows (Fig. 50). Mr. Morrison reports that: "We use an eight-gang *Fowler disc* to turn in all the legumes which does the work very satisfactorily, but for ordinary plowing nothing can come near the three-gang plows."

Another form of steam plow in use on a few plantations consists of a large single plow for making furrows. With the necessity in irrigated fields of having the furrows conform to the contour of the land, it follows that a cable-drawn furrow plow is only suitable to quite level fields. Where the conditions are right, however, it gives excellent service.

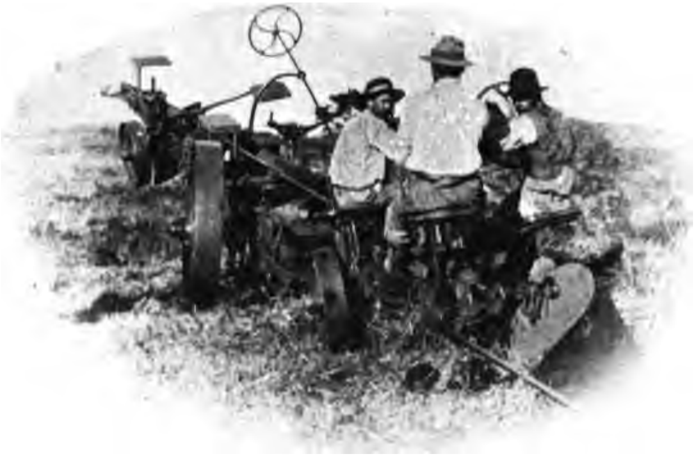

Fig. 51. A three-bottom Fowler in operation.

Before passing from the subject of steam plowing it would be unfortunate if we did not avail ourselves of a critical study of this work which was conducted by Mr. W. L. Paul, an expert of the John Deere Plow Company, who visited the Islands in 1913.

Mr. Paul has furnished the writer the following comments on his investigation:

> "We find a desire to have the soil plowed deep, but we invariably found that plowing was not done as deep as the planter desired, or as deep as the plowman thought he was going. We took many measurements, from which one can form his own conclusions.

"On one field we took a shovel and dug trenches across three or four furrows that had been plowed with a Fowler plow—did this at three different spots in the field. A diagram of the cross-section of these furrows is shown in Fig. 52 herewith.

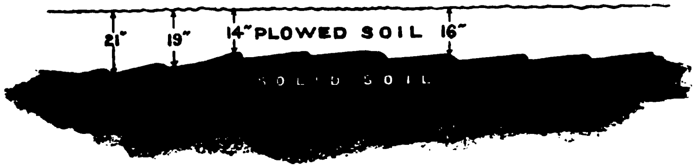

Fig. 52. Diagram of the depth of plowing of a Fowler three-bottom steam plow.
21" the deepest point, found once
14" the shallowest point
16" found often
17" to 18" average depth of loose soil.

Allowing an expansion of 20 to 25% in loose soil over solid soil, an actual depth of plowing would hardly exceed 14 inches.

"At another place we asked the engineer how deep he was plowing. He said sixteen inches. Here we took a stick of wood with a rather small end and long gradual taper, took thirty-one measurements in several places in the field by pressing the stick as far as the plowed soil would permit, alternately through the crown of the furrow and the lowest point of same (as indicated in Fig. 53), and the result was an average of about thirteen inches of plowing. This was second plowing, it previously having been plowed in the other direction.

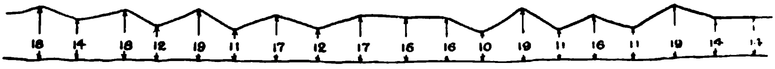

Fig. 53. Plowing measurements.

(Others were 16, 15, 15, 14, 15, 12, 14, 11, 14, 13, 13, 18, 12).

Thirty-one of these will average 15 inches. Allowing for expansion they give an average depth of plowing of about 13 inches.

"Perhaps they could have plowed deeper in any of these cases, particularly if the plow would not congest and if the bottoms would scour.

"We examined the plows and found the following dimensions, which naturally show how deep the ordinary Fowler plow is supposed to plow, if everything works correctly and conditions are favorable. (See Fig. 54). The gauge wheel *A* can be adjusted high enough to permit the point of share to go 16″ into the ground, leaving only ten to twelve inches clearance to the frame, which is perhaps sufficient when moulds scour and there is no trash on the ground.

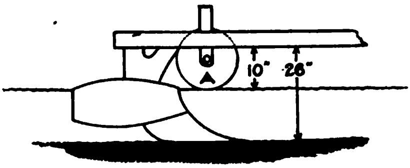

Fig. 54. Measurements of the ordinary three-bottom Fowler plow.

"When the shares strike a tough spot, the plow tends to raise from its work because of the counter balance in front, which, perhaps, accounts for the various depths and irregularly shaped furrows shown in the several figures.

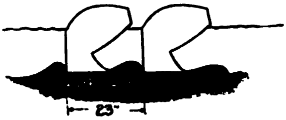

Fig. 55. Position of plow bottoms in service.

"Figure 55 shows another feature that perhaps is not noticed by everyone, because the work is covered up. The plows are set 23″ to 24″ apart, and the shares cut only fourteen inches, leaving nine inches undisturbed, and this may also account for the irregular bottoms of the furrows.

"The large single-bottom Fowler, of course, can plow deeper because of more clearance, and different adjustments, but this plow, we find, is seldom used.

"We also measured the work of the so-called *knifer,* with the following results: (See Fig. 56). We saw this machine go down until the bottom of frame cleared the soil 12″ to 14″, thus going from fifteen to seventeen inches depth. This was in a very stony field and, as the engineer said, there was no reason why they could not go down 23″, although this implement merely tears up the soil and does not turn it.

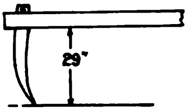

Fig. 56. The knife plow (*Fowler*).

"We have made these investigations because we expect to give the planter as good service—perhaps better, and with less expense—with our *engine disc plow*, with which we really have not yet shown our maximum depth. If more depth is desired, we feel confident it must be done with a disc plow, and I feel sure my Company will support me in saying we shall try to accommodate the situation.

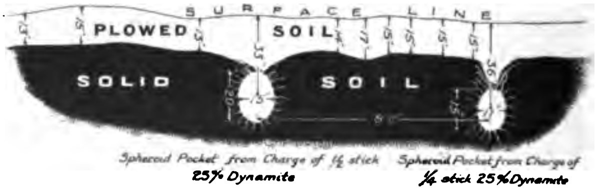
SURFACE LINE
PLOWED SOIL
SOLID SOIL
20
36
Spheroid Pocket from Charge of 1/4 stick 25% Dynamite
Spheroid Pocket from Charge of 1/4 stick 25% Dynamite

Fig. 57. Diagram showing:

1. Soil plowed by the single furrow plow shown in Fig. 48.
2. Unsuccessful attempt to shatter soil at greater depths by means of agricultural dynamite.

"A disc must scour and its revolving tends to turn trash under, where a mould board plow raises it first and increase the dangers of congestion.

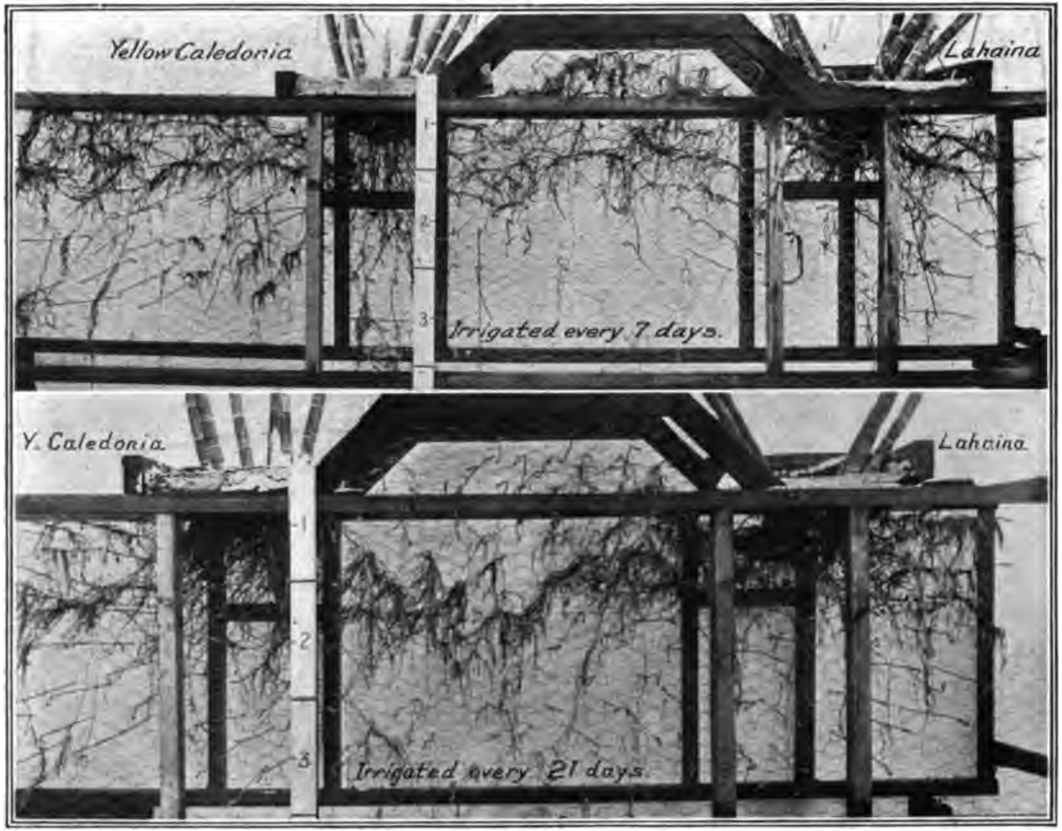

Fig. 58. Cane eight months old. Comparative root growth with 7-day and 21-day irrigations.

> "This is submitted for your consideration, and I also wish to offer my best energies towards having any improvements made that will give your planters desired results.
>
> "I may also give you further reports as the occasion arises."

The writer presents these opinions for one reason—that we may have the benefit of all viewpoints. Mr. Paul is unquestionably an authority on plows and plowing. Though we are not yet convinced that he is going to be able to show us how to do both better and cheaper plowing, we may say in deference to his claims that we are open to conviction.

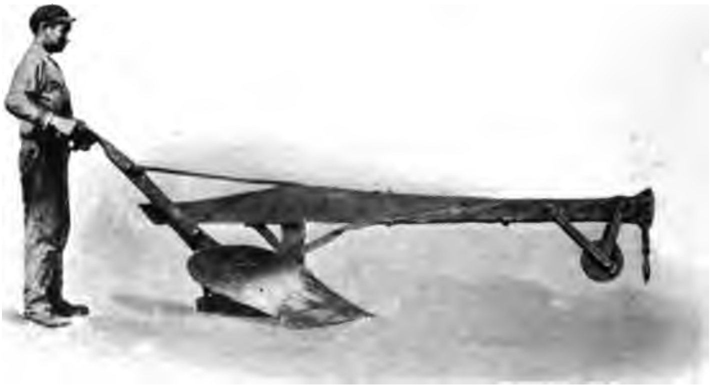

Fig. 59. A breaking plow—heavy home built type.

On submitting the question to the Honolulu agents of John Fowler & Co., they have favored us with the following:

> "Referring first to Mr. Paul's comments on the cultivation performed by Fowler implements we would say that, applying to certain plantations, they may be considered fairly correct. It is only fair, however, to point out that the particular pattern of Fowler plow to which he apparently refers has several variations in design. In the three-furrow plow of more recent development the bottom of the skife—or standard—reaches 28 inches below the beam, while the skid wheel may be adjusted to

allow of no more than six inches clearance below the beam, thus giving a possible plowing depth of 22 inches. Furthermore, these plows are in most instances equipped with 22-inch shares, which fact renders Mr. Paul's statement, as to width of furrow cut, somewhat open to correction, though true as regards the older pattern of this type of plow. The Fowler plow to which the writer refers has demonstrated that it will work with a minimum of congestion, and in conditions—such as those caused by wet weather—which would preclude any other type of plow from working at all. Plows of the particular design referred to are working on the lands of the Hawaiian Sugar Co., McBryde Sugar Co., Makee Sugar Co., Lihue Sugar Co., Hamakua Mill Co., and Hawi Mill & Plantation Co., while the same type of plow in somewhat modified form is working on other plantations in this Territory.

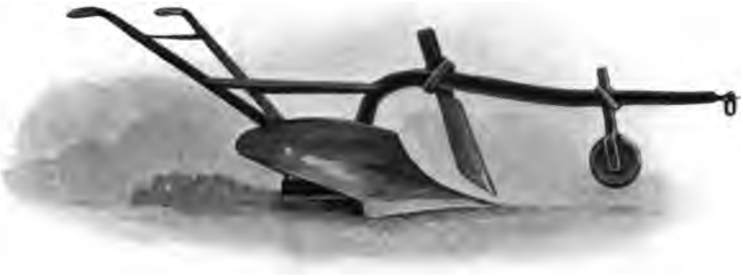

Fig. 60. Breaking plow (*Deere*).

"As to the Deere Engine Disc Plow, the design of this implement has certainly overcome one disadvantage which has been most strikingly in evidence in all other disc plows of American manufacture, in that the centers of the discs are set well below the beam, thus tending to decrease congestion."

We have taken occasion to follow Mr. Paul's plan of studying the depth of plowing and wish to add a little data that we have accumulated to that which he has furnished us, Forty-five measurements were made in a field which had been plowed in two directions by the thirty-six inch plow shown in Fig. 48. These varied from a minimum of 13 inches (found once) to a maximum of 22 inches (found twice). A general idea of the variation may be gained from the other measurements, which were:

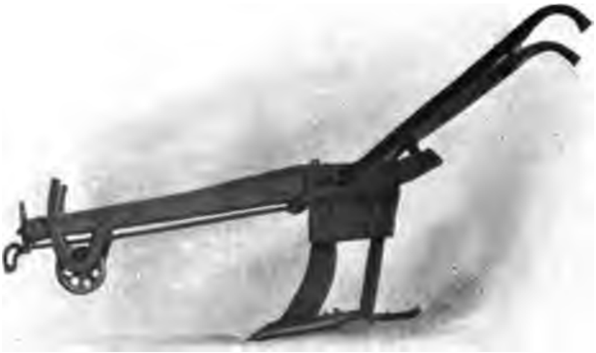

Fig. 61. Sub-soil plow.

21 inches—found	6 times.
20 “ “	7 “
19 “ “	10 “
18 “ “	9 “
17 “ “	4 “
16 “ “	3 “
15 “ “	1 “
14 “ “	2 “

Forty of the soundings were made at 5-foot intervals, while five were made at 1-foot intervals. The variation was approximately the same in either case. Perhaps the 20 to 25 per cent discount suggested by Mr. Paul would be a little too large in this instance as the soil had received one or two rains which must have exerted a compacting influence.

In a field that had been plowed in one direction by a 26-inch three bottom plow an average of 15 inches of loose soil was found in twenty-two measurements. The maximum was 18 inches (found once) while the minimum was but eleven inches (found three times).

Compared with less efficient work this is splendid plowing. Yet it is unfortunate that in some of the wonderfully deep soils of these Islands we must be content with breaking land to no greater depths than these. In our heaviest yields we have seen what it means for plant roots to feed to these depths as compared with shallow plowing. We thus have an index to what it will mean to enlarge our reservoirs of fertility by breaking the land still deeper, if we can only find a way to do it.

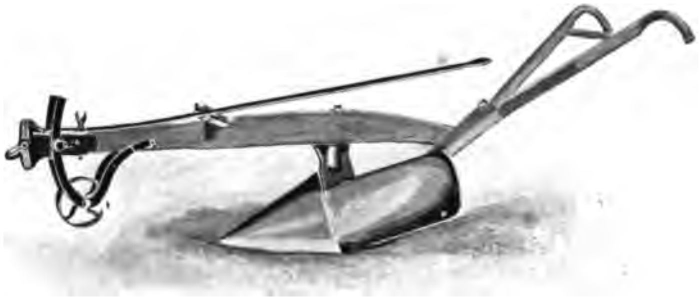

Fig. 62. Reversing plow for hillsides.

We have at the Waipio sub-station conducted some preliminary work in attempting to do this with agricultural dynamite (a 20 to 25 per cent product), of which so much has recently appeared in the agricultural papers. We must report, however, that thus far the results are extremely disappointing. Instead of shattering the soil in all directions with the massive cracks that are frequently pictured, we found on digging deep trenches that the discharge which occurred at three foot depths had merely compressed the soil, forming spheroidal pockets (Fig. 57) of a foot to 18 inches in diameter. It has been stated that success in this work depends entirely on the moisture content of the soil—if dry the soil shatters, if wet it puddles. We are therefore waiting to repeat our experiments under more favorable circumstances, for the moisture content of the soil was rather high. To be accurate, the soil gave 24 per cent of moisture on the dry basis at the depths in question.

The desirability of breaking soils to greater depths is further exemplified by the illustrations showing the root systems of cane after about eight months growth. The fertility of the subsoil is shown by the fact that the roots have descended beyond the depth of stirred soil, yet the greater bulk of the roots are confining their activities to the upper fifteen inches. Put the lower soil in condition for this great mass of roots to penetrate and we will get larger yields at lower cost—at less expense because irrigation water will be held longer by deeper depths of stirred soil.

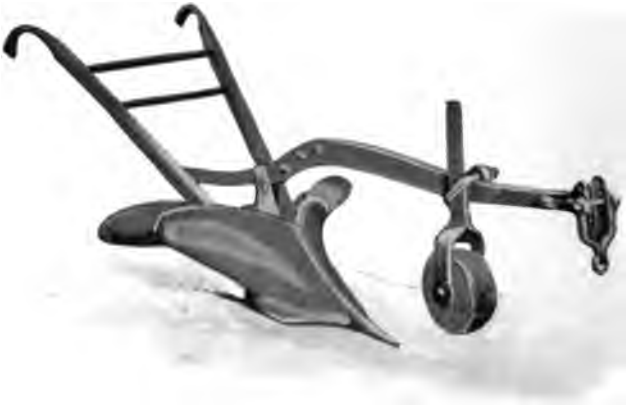

Fig. 63. A light furrow plow (showing wings attached to meet local conditions).

In Fig. 58 it is clearly seen that by irrigating at twenty-one-day intervals there is a decided tendency for the cane roots to seek a lower stratum than with seven-day irrigation. Loosen the soil to still lower depths and we can afford larger irrigations at longer intervals because we have provided larger soil reservoirs. A loose soil will hold more water than a compact one, just as an expanded sponge will hold more than a compressed one.

ANIMAL PLOWS.

There are a number of plantations where animal plowing still holds sway in breaking land. The conditions seem such as to demand it, either on account of the unevenness of the land, the shallow depth of the soil, or an inability to transport heavy plowing machines from one portion of the plantation to another where the fields are separated by deep gulches. Both the disc plow and the mould board plow have their advocates.

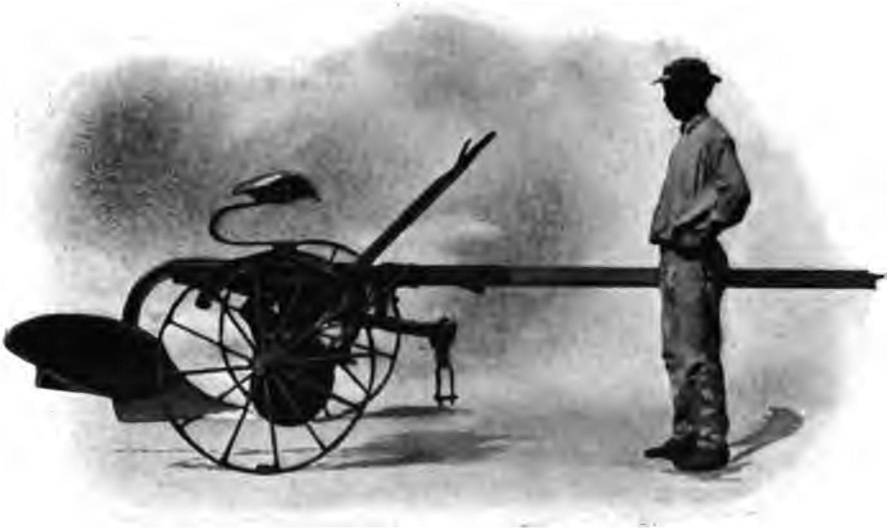

Fig. 64. A sulky plow (single mouldboard).

The mould board plows may be divided into two classes, the ordinary hand plow and the sulky plow. Hand plows for breaking land vary in size from ten to sixteen inches. A fourteen inch plow is shown in Fig. 59, and illustrates the type of the heavy, substantial, plantation built implement, which claims durability as a chief asset. Aside from these plows which are constructed wholly or in part by the plantations, one finds such standard makes as the *Oliver*, the *Deere*, the *Moline*, and the *Avery* well represented.

One of the more modern forms is shown in Fig. 60. That there are other considerations than durability to be reckoned with in plows, is no less a fact because some of them are hidden from casual observation. Some day we may appreciate this to the extent of making our choice in plows upon comparative draft tests and the like. An idea may be gained of the amount of money which is needlessly expended as a result of poor efficiency in plowing when we are reminded that the annual plowing bill of the United States may be estimated at approximately four hundred and fifty millions of dollars, and that "experiments go to show that very common causes effect increases of from 5 to 40 per cent each in the draft."

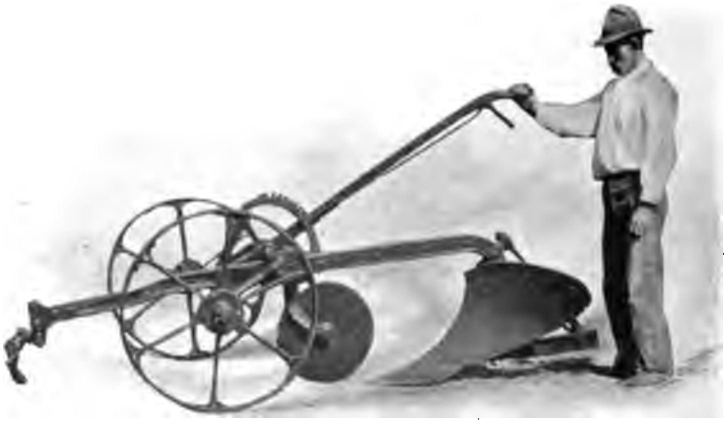

Fig. 65. Sulky plow (double mouldboard for furrowing).

Proceeding further into a discussion of this topic we read from Ellis and Rumely:

> "The draft data given in the following paragraphs are derived from numerous sources, the chief of which are the plow trials conducted by the New York Agricultural Society at Utica in 1867, and reported by Gould; tests in Missouri and Utah two decades ago by Sanborn; and in Illinois by Ocock in 1904. The earliest of these trials were the most comprehensive, but since then great im-

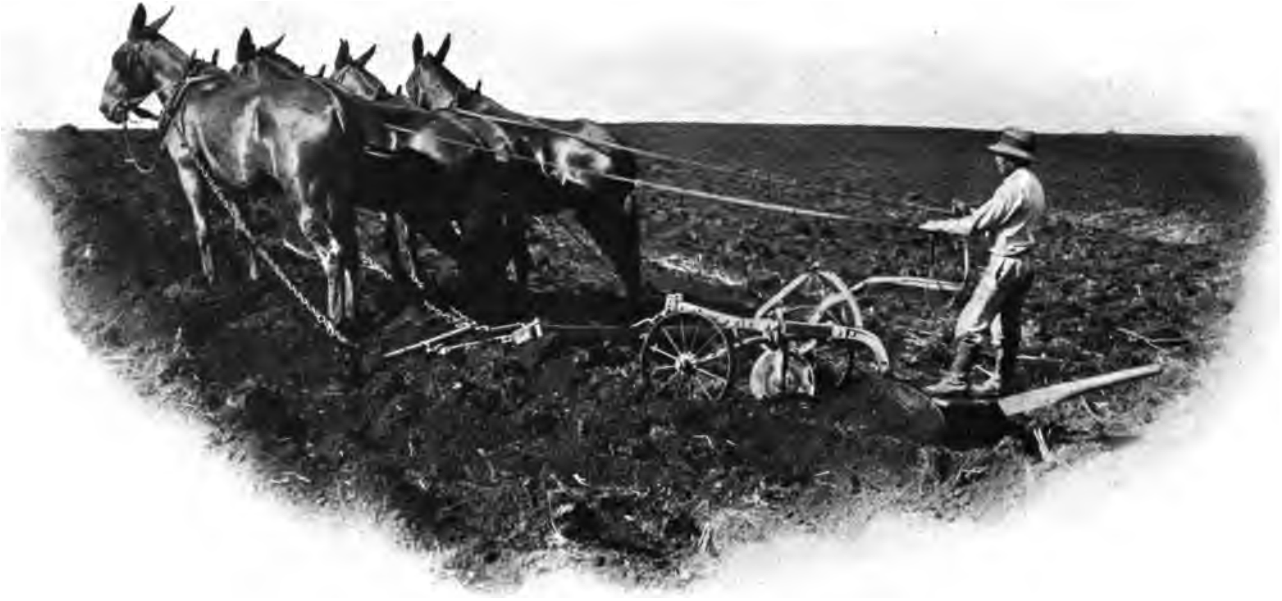

Fig. 66. A modified sulky furrow plow.

provement has been made in both plows and dynamometers, and tests of modern plows might not bear out the conclusions drawn at that time. It is extremely unforunate that the draft tests have received so little attention from agricultural engineers, and that no comprehensive data are available as to variations in the draft of all modern implements.

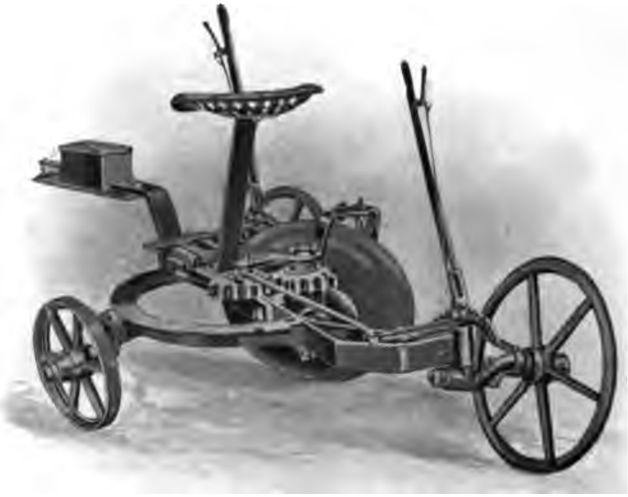

Fig. 67. The reversible disc (*Benicia*).

"The plow runs lightest when so adjusted as to allow the sole of the landside to run level from point to heel; to cause the line of draft to pass at the same time straight from the centre of resistance through the attachment at the end of the beam to the point where the power is applied, and to render the angle of draft—i. e., the angle of the line of draft with the base line—as small as the application of power will allow. The location of the centre of resistance varies with the character of the soil, the shape of the plow, and the size of the furrow. If power could be applied at the centre in a horizontal line, the plow would move with the least possible draft and with perfect balance. Obviously, however, it must be applied at a higher point, varying with the power used, and this lifting force must be overcome either by adjustment of the plow or by pressure on the plow handles. In the same way, if power is applied to the right or left of the centre, an opposed force must be exerted to make the plow run evenly.

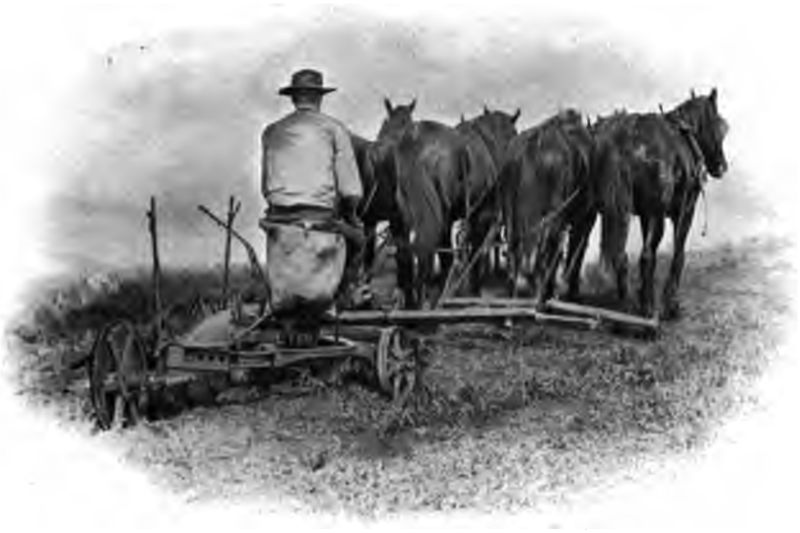

Fig. 68. The reversible disc in operation.

"The true line of draft is always from this centre to the point where power is applied; hence any enforced angle, such as caused by sagging of the traces, holding up the traces by straps, extending or shortening the beam, and raising or lowering the draft pin in the clevis, disturbs the adjustment. The determination of the centre of resistance is, therefore, important.

"Since the greatest effort is expended by the shin and share in severing the furrow slice from the land, the centre must lie much nearer the landside than the furrow side of the plow. Again, since the resistance of the cutting edge of the share and the sole are greater than that of the mould board, the centre must lie nearer the sole than to the crest of the mould board. A third plane of resistance stands perpendicular, at right angles to the landside. Cross sections of the plow in planes at different distances from the point show triangular areas increasing more rapidly in size than the cutting edges do in length. The force required to drive the plow into the ground does not increase in proportion to the area cut, and the centre of resistance will lie in a smaller cross section than that of the whole furrow.

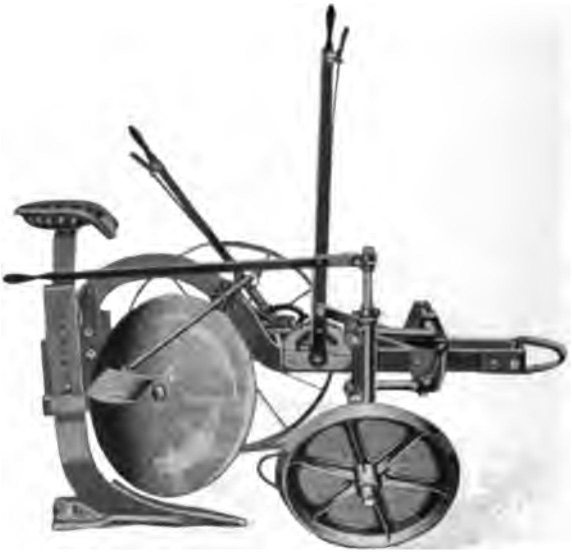

Fig. 69. Disc plow with sub-soil attachment. (*Deere Secretary*).

In other words, it will lie much nearer the point than the heel of the share, being farther forward in stiff soils, in sallow plowing, and on a rather blunt plow point, than under reverse conditions. The centre lies at the intersection of the three planes, and its approximate location must be known in order to adjust the point of hitch so that it will fall naturally within the line of draft. On stubble and general purpose plows it will lie close to the shin and to the junction of share and mould board. On plows designed for breaking tough sod at a shallow depth it will lie closer to the point and the sole. Professor Gilmore, of Cornell University, states that it is located behind the mould board and two and one half to three inches from the wall and sole of the furrow. No other condition within the control of the operator so vitally affects the resistance of the plow as the one just reviewed, and success demands careful observance of the principles governing the lines of draft and resistance.

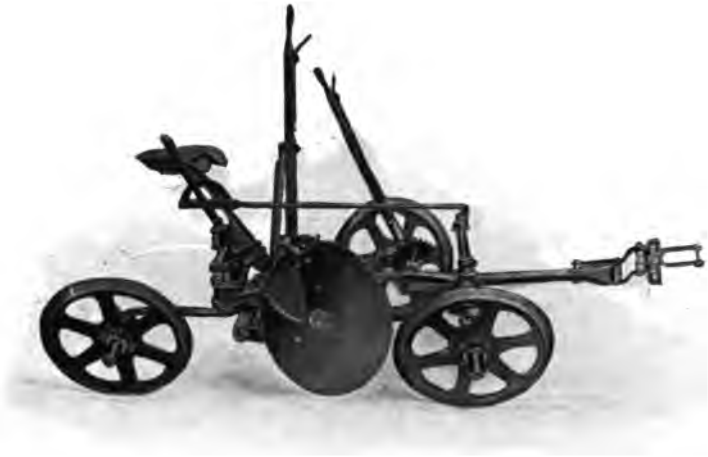

Fig. 70. Single disc (*Deere*).

"According to Sanborn, the plow shows the highest draft when set to cut the widest furrow of which it is normally capable. This is probably accounted for by the remarkable results of an experiment at the Utica trials which showed that 55 per cent of the draft of the plow was caused by the cutting of the furrow slice, 35 per cent by the friction of the sole, and only 10 per cent by the work of lifting and turning the furrow. The average draft of a number of plows running in the empty furrow was 168 lbs. The whole draft was 476 lbs., and that with the mould board removed 434 lbs. The difference between 168 lbs. and 434 lbs. was taken to be the draft required for cutting the furrow slice. Sanborn states later that 42 per cent of the draft is used by the share and landside, and another writer puts the mould board friction at only 2 per cent. These figures will not hold for all conditions, but even an approximate idea of the division of draft explains many frequently observed facts.

"In relation to the size of furrow, the cutting edge should be as small as possible. A furrow 4x12 inches has a line 16 inches long which must be cut, and an area of cross section of 48 square inches, a proportion of 1 to 3. One 6x14 inches has a cut surface of 20 inches and an area of 84 square inches, a ratio of 1 to 4.2. The larger the furrow cut, therefore, the less the influence of the cutting edges on each square inch of cross section, which is the commonly accepted unit of comparison. Sanborn found a constant decrease in draft per square inch as the furrow was deepened or widened up to the normal capacity of the plow. When made to cut wider, narrower, shallower, or deeper than the adjustments of the plow ordinarily permitted there was an increase in draft of 15

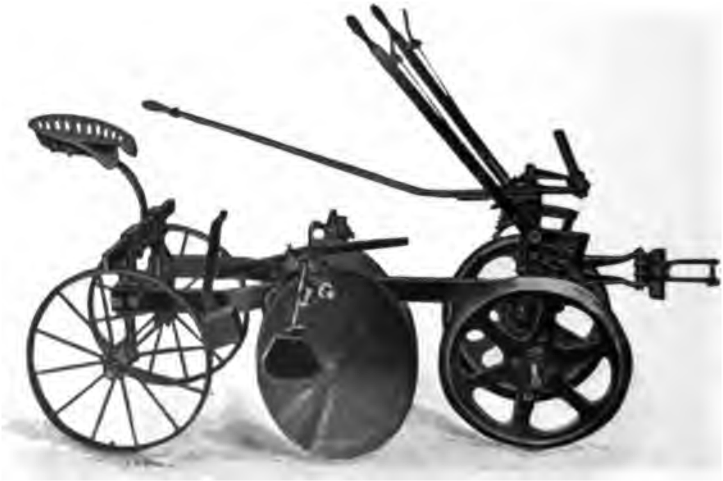

Fig. 71. A disc bedder (*Deere*).

to 20 per cent, much harder work for the plowman and a poorer quality of plowing.

"The point of hitch is lower on a plow than on a wagon. Frequently a strap is provided at the saddle or rump to hold up the traces while the team stands. When the same team and harness are used on the plow an angle is formed at the trace. Sanborn found the downward pull at this point to equal 50 lbs., or one-third the pulling power of an average 1200 to 1500 lb. horse. The angle was not as great as he had frequently observed, but even then a third of the animal's power was being used to gall and annoy it instead of being applied to the work in hand."

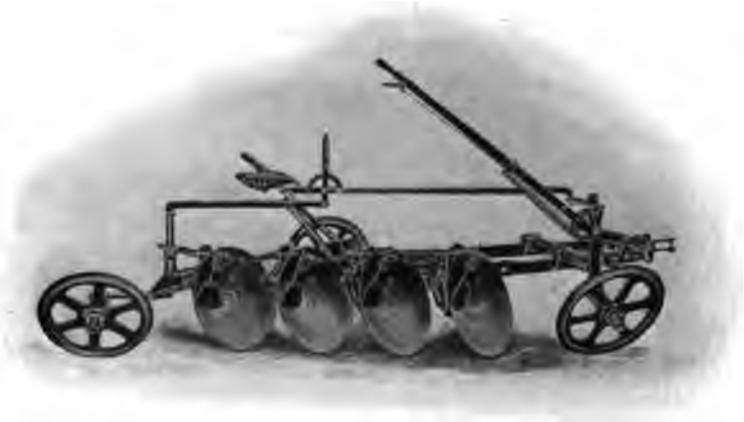

Fig. 72. Quadruple disc plow (*Deere*).

Without quoting at greater length from the draft tests as described by Messrs. L. W. Ellis and Edward A. Rymely, we would recommend their work "The Power and the Plow"* as a valuable asset to plantation libraries. .

Proceeding to other types, a subsoil plow such as is illustrated in Fig. 61 is also found to be occasionally employed in breaking land.

The hillside plow finds a place on some plantations. (Fig. 62). It consists of a single mould board that may be reversed from one side to the other, always throwing the furrow down hill.

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* Doubleday, Page and Co., 1911.

Two types of furrow plows have been referred to under implements used in hilling cane. A third and much lighter form is shown in Fig. 63. It is customary to modify factory-built plows of this nature by the attached wings as shown in order to meet local conditions.

SULKY PLOWS.

Sulky plows, consisting of the ordinary single or double mould board plows mounted on wheels are illustrated in Figs. 64 and 65. This type has several enthusiastic advocates here in the islands. The merits of the sulky plow are fittingly summed up by the aforementioned authors in saying:

> "The friction of the plow sole, estimated at 35 per cent" (of the total draft) "is transferred almost entirely to wheels in the sulky plow. The landside is made much shorter, and the heel of the latter is usually carried a fraction of an inch from both the bottom and side of the furrow by means of a staggered wheel. The lifting of the soil is borne by the larger wheels and frame, while the relatively small mould board friction remains constant. Sanborn shows only .19 lb. per inch, or 3.3 per cent. difference in draft in favor of walking over sulky plows. averaging three tests of each, but observes that the draft of sulky plows increased on the hills. Considering amount and quality of work, the difference in draft is negligible. In fact, an unskilled plowman will even cause greater draft in a walking plow by constantly disturbing its adjustment. The influence of the operator's efforts to help the adjustment was seen in one trial in which different plowmen in successive furrows varied the draft from 5.19 to 4.45 and 5.61 lbs. per inch, respectively, while another on several trials ranged from 5.25 lbs. to 6.15 lbs. A small truck or gauge wheel under the beam of the plow should, theoretically, increase the draft by adding friction and by frequently disturbing the line of draft as it encounters obstructions. Practically it is shown to save from 9 to 14 per cent by the steadier running of the plow when it and not the handles, is used to regulate the depth."

A rather unusual departure in the sulky plow is shown in Fig. 66. Here the weight of the teamster is borne on the plow itself instead of by the wheels, and the draft is increased accordingly.

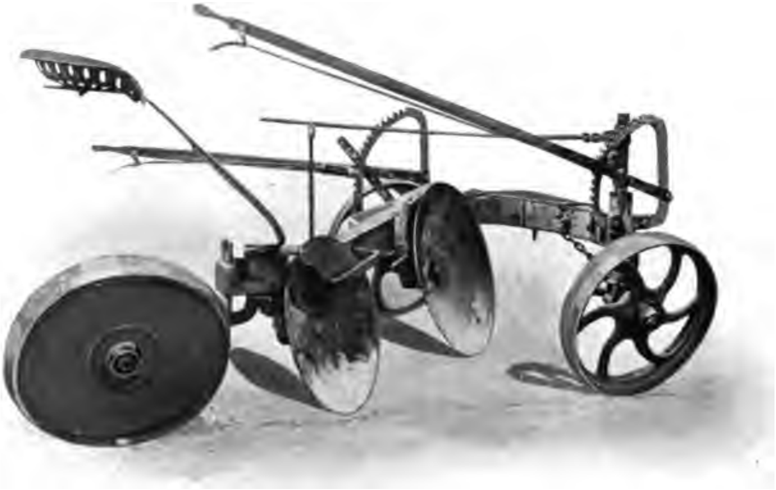

Fig. 73. Deep tilling machine (*Spaulding*).

DISC PLOWS.

A still further modification of the sulky type is found in the disc plows which have become so popular in Hawaii and elsewhere. Before proceeding to the different forms found on the plantations it is well to quote Davidson of the Iowa State College who, in discussing the comparative merits of disc and mould board plows, has this to say:

> "In soils where the mould board plow will do good work there is nothing to be gained by the use of the disc plow. The draft is often heavier for the amount of work done and the plow itself is more clumsy than the other form. However, in sticky soils where the mould board will not scour, the disc plow can often be made to do good work. Again, in very hard ground, where it is impossible to plow with the mould board plow, the disc will work, and appar-

> ently with much less draft. The manufacturers of both disc and mouldboard plows are now recommending generally the use of the latter for soils where it does good work."

According to Ellis & Rumely "this opinion is supported by that of other prominent agricultural engineers, and may be accepted as presenting adequately the adaptation of the two types."

The disc plows most commonly found hereabouts are the *Benicia Reversible* (Figs. 67 and 68) and the *Deere Secretary Disc* (Fig. 69) which has a subsoil plow in addition to a revolving disc. Both of these implements are very popular, some plantations expressing a preference for one, while on some places the other is in distinct favor. Both are undoubtedly very efficient. On account of its reversible nature, the Benicia plow is very desirable for breaking lands on hill sides. By operating it alternately as a right handed and left handed disc, the soil is thrown down grade all the while.

A single disc plow of the non-reversible type is also used extensively. It is illustrated in Fig. 70.

The *Deere quadruple disc plow* (Fig. 72) is used to a limited extent in the Kohala district. Its draft is too heavy for primary breaking, but for re-plowing and turning under a volunteer growth of weeds or a green manuring crop of legumes, it does satisfactory work.

A *disc plow for bedding* (*Deere*) is shown in Fig. 71. This implement has been successfully employed on one or two plantations in making furrows and also in off-barring. It has been found to be a very satisfactory tool to use in throwing earth over cane trash which is allowed to remain between the rows.

The *Spalding deep tilling machine* is a comparatively new implement. (Figs. 73 and 74). It was first introduced into the Islands by Mr. C. H. Wilcox, formerly manager of the Koloa Sugar Co. Two discs, one set lower than the other and mounted on a frame of sufficient weight to hold them to their deep plowing, is the secret of the excellent work of this device. Mr. James Webster of Pepeekeo reports that he has successfully employed the Spalding machine for turning under cane-trash. This alone should more than warrant the increased attention that is being accorded it.

"It is so arranged," said Mr. Webster in referring to the Spalding device (1912 annual meeting) "that the front disc takes a slice off the top, turning it into the bottom of the previous furrow. This slice may be of any depth desired. The second disc comes along about four inches inside the track of the other and can also be set at any depth, dependent on the depth of slice taken by the first. Coming along as it does on the space cleared of all grass and stumps of cane by the first disc, it effectively covers them up and turns up a perfectly clean and well-pulverized seed bed.

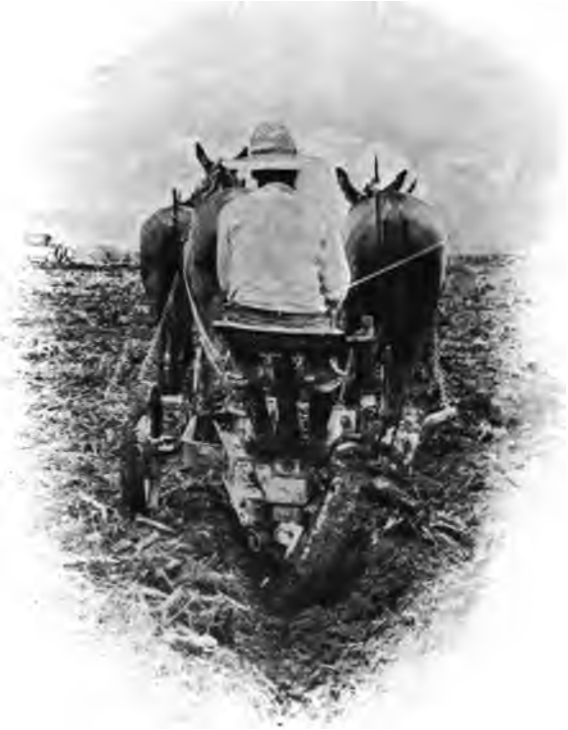

Fig. 74. Second plowing on a field where trash was left. (*Spaulding deep tilling machine*).

> "I intend to use it to turn under trash and see no reason why it should not do it. We did not have to use it on trash this season, but turned under some pretty rank grass.
>
> "The draft is about the same as the *secretary disc*, giving five animals all the pulling they want. It is readily adjusted as to depth and width of furrow, handles for regulating being right alongside the driver. The only weak point I discovered about it was in the quality of the discs, which are too soft."

In discussing the returning of cane-trash to the land at the 1913 annual meeting Mr. Webster reported that:

> "The weak point heretofore has been in not being able to turn in the trash, in round plowing for planting. This has been overcome with the advent of the *Spalding deep tilling plow*. This season I plowed under a small area, being afraid to get too much area lest we would be unable to get a furrow plow through it. Fears were needless as after a month all that remained of the trash was a skeleton. There was a good deal of grass and *honohono* besides the trash which was never heard from again."

It seems to the writer that it should only be a step to adopt the principle of this plow to a still larger, still heavier, device suited to the Fowler steam-plowing tackles.

THE RELATION OF THE TRASH-MULCH TO IMPLEMENT WORK.

The matter of returning trash to the land is going to largely revolutionize the use of implements in the Hawaiian Islands once it becomes a general practice.* Many of the implements mentioned in this review will be forced into the scrap-heap, while others yet untried will no doubt come into service.

Returning trash makes the use of implements to a large measure less necessary. *The loose, friable, tilth of soil that comes from mixing organic matter with it, is a far more effective, a far more permanent tilth than comes from loosening soil with implements.* So it is only fair to say that the implement question becomes somewhat less important as we learn that we can leave trash between cane rows of a ratooned field. On the other hand it will be found as we go into this work that there are many fine points and many differences of opinion on how to handle this trash to best advantage.

---

* See "Record" June, 1914.

Mr. Webster's present system as described by Mr. Larsen is about as follows: At a suitable time after cutting, the cane fields are pali-palied, that is, the trash is hoed away from the stools into the middle of the furrow. After this the cane is off-barred with 10-inch to 14-inch plows. This operation throws some soil on the trash but does not cover it entirely. If a revolving coulter is attached to the plow it gives a clean cut ahead of the plow, and makes neater work of it. Subsequently, when the trash has become brittle, cultivators may be run over the trash, scattering it and at the same time intermixing a certain amount of soil. As the trash rots small plows finish the task of working it into the soil. Afterwards the cane can be hilled in the conventional manner.

If we turn to foreign parts for ideas in combining implement work with leaving trash, we find that in Cuba, Earle has suggested leaving alternate rows bare of trash by simply placing the trash of the two rows into one. This idea loses some of its simplicity when the trash amounts to a heavy blanket of some twenty tons. Nevertheless we must quote Mr. Earle for the benefit of those who object to the trash proposition because it interferes with ratoon plowing.

"As soon as the cane is cut" he suggests "take an ordinary horse rake and drive so as to cross the rows, raking the trash from one middle and dumping it into the next one. This quickly and cheaply clears half the ground so that it can be plowed and cultivated and provides a double mulch of trash for the other half, which makes it so thick and heavy that practically no weeds can come through and these middles will require no further attention for the season. Now plow the cleared middles with a two-horse turning plow, throwing the dirt away from the cane. Run the last furrow as close to the cane stubble as possible." He further recommends that these middles be kept well cultivated and that before the cane closes in they should be planted to legumes.

It remains to be seen whether this plan will work in Hawaii where our trash is so much heavier than it is in Cuba, but we cannot neglect the opportunity of finding out.

A plan which we have developed at Waipio for handling a heavy mass of trash on irrigated lands consists essentially of bundling the trash and leaving it. This method as suggested by Mr. W. P. Naquin assures the successful handling of trash under very difficult circumstances. In many cases it may prove more expensive, hence less desirable, than merely piling the trash between the cane rows, and repiling it or holding it in place with a little earth as occasion demands. The main point is that by one means or another trash can be successfully returned to the soil. Where the cane is hilled as in old ratoons, the trash lies in the water furrows. The objection may be raised that this impedes the progress of irrigation water. If such proves to be the case the bundles from two rows can be crowded into one and the water can be run in the bare rows, in which event we may use implements to advantage, as per the Cuban plan. Irrigating in alternate rows was reported upon by Mr. F. F. Baldwin at the 1912 annual meeting as a successful method of making a little water go a long way. If, however, the odd rows were covered with a heavy moisture-conserving mulch of trash, does not the every-other-row method assume promise of becoming something more than an expediency in time of drought?

These points are mentioned for two reasons: First, to show that we have hardly begun the study of the fine points of this trash question. Second, the trash proposition does not necessarily obviate the use of implements.

If there is anything to be gained by uniting these two factors in our future field methods, there is more than one way of going about it.

IN CONCLUSION.

The writer has thus attempted an account of such sugar-cane implements as have come under his observation in Hawaii. He is conscious of the fact that he has only skimmed the surface of a very important subject. Yet it is hoped that this compilation may lead to a still closer interchange of ideas on cane cultivation as it now exists in different parts of these Islands; and if by any chance this should prove the nucleus for new ideas or further developments, these notes will then have served their purpose best.

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AGRICULTURAL AND CHEMICAL SERIES BULLETIN No. 45

REPORT OF WORK
OF THE
EXPERIMENT STATION
OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

A Study of the Principal Plantation Soil Types as Found on the Island of Hawaii.

BY P. S. BURGESS

HONOLULU, HAWAII
1917

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LETTER OF TRANSMITTAL.

To the Experiment Station Committee
of the Hawaiian Sugar Planters' Association,
Honolulu, T. H.

Dear Sir:—I submit herewith for publication as Bulletin No. 45, of the Agricultural and Chemical Series, a paper by Mr. P. S. Burgess, Chemist, entitled "A Study of the Principal Plantation Soil Types as Found on the Island of Hawaii."

Yours very truly,

H. P. Agee,
Director.

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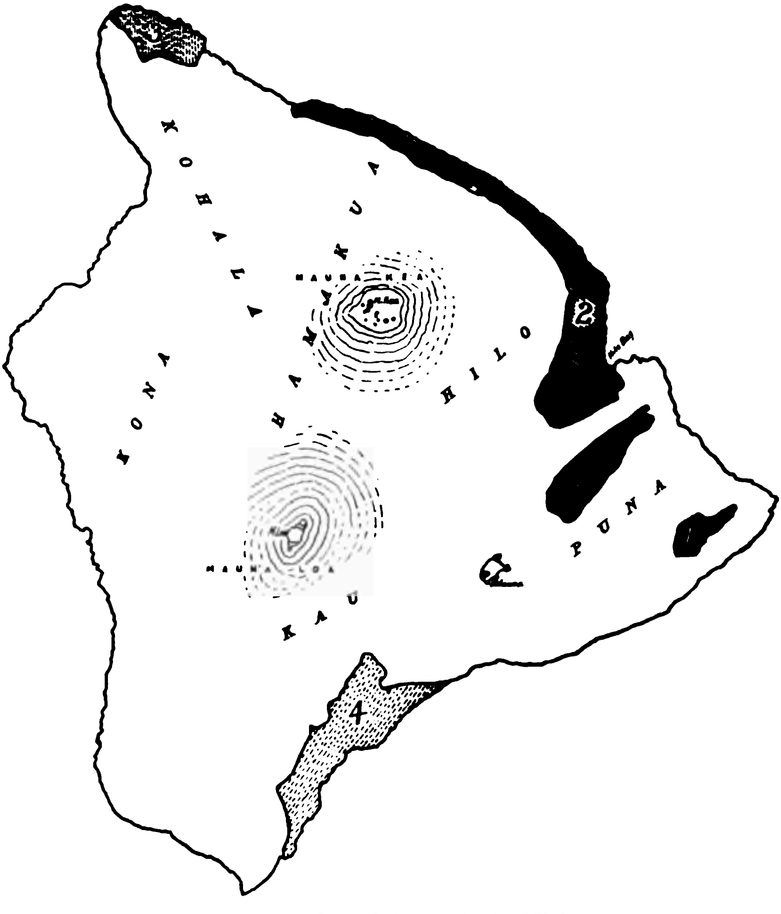
INTRODUCTION

The object of this Bulletin is to place before those who control the plantation lands of Hawaii certain scientifically-gleaned facts, a few of which it is hoped may be of value to them in the management of their acres. No industry is so vital to the prosperity of these Islands as agriculture, and nothing is so vital to agriculture as the soil. Fertility, or the power of a soil to produce crops, is here a subject worthy of study and experiment. Millions of dollars are spent each year in fertilization. To produce maximum crops at minimum expense and with an increase instead of a loss in productive capacity! This is the object. The necessity for more knowledge concerning soils and soil fertility is apparent.

The Island of Hawaii is the largest of the group. On it are located twenty of the forty-five sugar-growing plantations. These produce about 35% of the entire sugar crop of the Islands. Hawaii possesses more different and distinct soil types than appear on any of the other islands. Up to this time, however, no systematic study of these soils has been attempted. This Bulletin deals with the chemical composition, certain of the physical characteristics and the more important biological changes taking place in the chief plantation soil types here encountered.

In appreciation of the fact that the practical application of results secured in the laboratory must be made by the men who control the land, I have so far as possible endeavored to write into the discussions the practical interpretations, and it is believed that certain of the data herein presented will be of intrinsic value to the plantations concerned. P. S. B.



SOIL DISTRICTS ON THE ISLAND OF HAWAII.

1. Hilo-Puna District.
2. Hilo and Hamakua Coast District.
3. Kohala District.
4. Kau District.

A Study of the Principal Plantation Soil Types as Found on the Island of Hawaii.

By P. S. Burgess.

CHAPTER I.

General.—The Soil. Its Formation, Physical, Chemical and Biological Properties.

The land surface of the earth is almost everywhere covered by a thin layer of unconsolidated material which we term soil. As defined by Hilgard, "a soil is that loose, friable material in which plants, by means of their roots, may find a foothold and nourishment, as well as other conditions necessary for their normal growth."

Soil formation is a subject of much geological and agricultural importance. Tersely stated, soils are formed by the decay and decomposition of rocks and plants. This conversion of rock into soil has been accomplished as a result of various agencies. Some are of a mechanical or physical nature, others are chemical. The physical processes influencing soil formation are: changes of temperature, moving water and ice, wave action, winds, and plant and animal life. Let us discuss each briefly.

Changes of Temperature. All rocks are mineral aggregates. Very few minerals expand and contract alike if subjected to different degrees of temperature. This is due to chemical composition, to structure and in part to color. Thus, with ever-changing temperature, minute cracks are formed, resulting in a final disrupting of the rock mass. This is especially noticeable at high altitudes, where there may be a difference of over a hundred and twenty-five degrees (F.) during each twenty-four-hour period. Rocks with definite lines of cleavage (stratification planes) are more susceptible to temperature changes than are massive, structureless rocks.

Moving Water and Ice. The action of flowing water is one of the most potent agencies in soil formation.

The continual dropping of rain on the softer and more weathered rocks gradually wears them away; and, as this water, laden with mineral particles, runs to lower levels, the surfaces of the rocks over which they pass are in turn abraded. All of this material is ground finer as it is carried on, the fineness depending upon the original size of the mineral grains and the rate of the stream. This soil material is sorted and finally deposited, forming the great areas of deep alluvial soils found throughout the broad valleys of the world. (The enormous erosive power of moving water is convincingly shown by the stupendous gorges of the Colorado and Columbia rivers in the western United States; the former cut to a depth of over 5000 feet through solid granite and basaltic rock.)

On slopes where water flows only during heavy rains or melting snows, this same erosive effect may be seen. These Islands afford a perfect example of such action. Wave action along the coasts may also be mentioned, as here large rocks are in time ground up to form sand which later may become soil. Water freezing in the crevices of rocks as well as glaciers moving over the surface of the earth all tend to fine, to wear away, and eventually to produce mineral powder which only awaits the life of the plant and the animal to convert it into soil.

Wind. The effects of wind blowing across the loose surface of the earth are well known. The fine, sharp, wind-borne, mineral particles acting as tools, wear away large areas of exposed rock surface. This is especially true in the great desert areas where violent sandstorms often occur. In humid regions this form of disintegration is less marked; nevertheless, in sandy sections it often performs effective work.

Plant and Animal Life. In the soil-forming processes the work performed by plants and animals is both mechanical and chemical. The roots of plants growing in the crevices of rocks pry them apart and loosen them, while burrowing animals of all kinds continually expose fresh rock surfaces to other weathering agencies. Plants materially assist in making soil by contributing their dead remains. This constructive work is essential to soil formation, for it is by this means that organic matter and humus are supplied. The organic acids, including carbonic, formed by bacteria during organic decomposition, tend to dissolve certain of the more soluble minerals and further assist in rock disintegration. The earthworm and other low forms of animal life take the soil particles through their bodies, mixing them with their intestinal juices, thus increasing their solubility and decreasing their size. The earthworm, on account of its habits and abundance, is probably the most important of all soil-forming animals.

While the physical agencies above mentioned are of most importance to soil formation in arid and semi-arid sections, the chemical processes of decomposition are probably more effective in the warmer, humid zones.

The more prominent chemical soil-forming agencies are the following: solution, hydration and oxidation, carbonation, and humification.

Solution. Pure water will dissolve minute quantities of all minerals, but the action is very slow. The soil moisture, however, is not pure water, but a weak solution of several organic acids (chiefly carbonic). Experiments by Headden of the Colorado Agricultural Experiment Station have shown that carbonated water will dissolve over nine times as much mineral matter from soil as will pure water. Carbonated water has been termed "the universal solvent" by Hilgard, and it is the solvent action of this weak acid solution which is of interest to us in a study of soil formation. The soil water is constantly in motion and the processes of solution and reprecipitation are at all times taking place.

Hydration and Oxidation. The chemical addition of water and the element oxygen are termed hydration and oxidation respectively. These processes are constantly taking place on all exposed moist rock surfaces. Both are softening processes. Both also tend to cause expansion and increase the bulk. Zones in decaying rocks which have undergone these chemical changes may be readily distinguished and are much more easily acted upon by other weathering agencies.

Carbonation. This is the union of the acid radicle CO_2 with certain of the compounds in the rock to form the more soluble carbonate and bi-carbonate. The elements carbonated are usually calcium, magnesium, sodium and potassium. This process is of prime importance in the breaking down and solution of limestones.

Humification is the broad term used to denote the degredation and decay of dead plant and animal remains, present in all soils, with the final formation of those dark-colored organic substances which collectively we term humus. The growth and multiplication of bacteria are here essential. While this process is chiefly concerned with the organic fraction of the soil, it has an indirect bearing upon the mineral fraction as well, for many organic acids are thus formed which keep the soil solution charged, and this, in turn, acts upon the mineral grains.

The higher the temperature and humidity (within certain reasonable limits) the greater will be chemical action in soil formation.

Soil-forming Minerals. While the several processes of soil formation have a decided influence in determining soil character, the differences in the rock from whence soils have been derived also produce profound variations. The original country rock is not only the source of all the inorganic portion of the soil, but it also greatly influences the character and amount of the organic fraction.

Of the eighty-odd elementary substances (termed elements) known to science, less than twenty occur in any quantity in the earth's crust. Estimates of the proportions in which the more abundant elements contribute to the composition of the earth's crust (including the sea and atmosphere) have often been made by geological chemists. The latest and most widely accepted of these, by F. W. Clarke of the U. S. Geological Survey, appears in the table which follows:

Relative Proportions of the More Important Elements Forming the Earth's Crust.*

Oxygen	**49.98%**	**Carbon**	**0.21%**
Silicon	**25.30**	**Chlorine**	**0.15**
Aluminum	**7.26**	**Phosphorus**	**0.09**
Iron	**5.08**	**Manganese**	**0.07**
Calcium	**3.51**	**Sulphur**	**0.04**
Magnesium	**2.50**	**Barium**	**0.03**
Sodium	**2.28**	**Nitrogen**	**0.02**
Potassium	**2.23**	**Fluorine**	**0.02**
Hydrogen	**0.94**	**Chromium**	**0.01**
Titanium	**0.30**		

As will be seen, 98% of the earth's crust is composed of the first eight elements, 50% of which is oxygen. Approximately 86% of this oxygen is contained in the solid rock, from whence it follows that practically all of the elements exist in combination with it as oxides. All of the complex minerals contain oxygen and most of them silica. The proportions of the chief soil-forming minerals as given by D'Orbigny appear below.

The first column presents the name of the mineral; the second, the elements which are chemically combined to form it, and the third, its estimated percentage in the solid crust of the earth.

Mineralogical Composition of the Earth's Crust.

Mineral.	Elements Present.	Percentage.
Feldspars	Silicon, aluminum, sodium, oxygen, calcium, potassium	48
Quartz	Silicon, oxygen	35

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* U. S. Geol. Survey, Bul. 491.

Micas	Silicon, hydrogen, sodium, oxygen, potassium, aluminum	8
Talc	Silicon, hydrogen, oxygen, magnesium	5
Carbonates	Carbon, calcium, oxygen, magnesium.	1
Hornblend, augite and olivine	Oxygen, magnesium, aluminum, silicon, calcium, iron	1
Rarer minerals and weathered products	All other elements	2
		100

With the exception of coral formations, all of the rocks from which soil has been formed on these Islands have been of direct volcanic origin. We term these rocks "basaltic lavas," due to the great preponderance of chemically basic elements from which they have been constructed. Clark, after studying hundreds of analyses of basaltic lavas from different parts of the world, finds their average mineralogical composition to be as follows:

Average Mineralogical Composition of the Igneous Rocks of the Earth's Crust.

Mineral.	Percentage.
Feldspars	59.5
Hornblend and pyroxine	16.8
Quartz	12.0
Biotite mica	3.8
Titanium minerals	1.5
Apatite	0.6
	94.2

This leaves 5.8% to be divided among the rarer minerals.

The inorganic portion of all soils, as formed from the weathering of these minerals, is made up chiefly of the oxides and hydrated oxides of the elements silicon, calcium, magnesium, iron, aluminum, sodium and potassium, with smaller amounts of phosphorus, sulphur, titanium and manganese and traces of many of the rarer elements.

With this brief discussion of the agencies of soil formation and the minerals from whence soils are derived, we will proceed with the more important physical, chemical and bacteriological properties of arable soils as they exist today.

PHYSICAL PROPERTIES OF SOILS.

The important physical characteristics of soils are color, weight, texture and structure, temperature, moisture relations and absorptive properties.

Color. A great variety of colors are displayed by soils of different chemical compositon. They vary from black to almost white through many shades of brown, red, gray and yellow. These colors are due chiefly to organic matter (humus), or lack of it, and to different compounds of iron. The dark-colored soils, due chiefly to much humus and the presence of ferric iron, are, as a rule, rich soils, while those of lighter hue are apt to be less productive. Limestone soils, as well as certain light-colored soils in arid regions, may be considered as exceptions.

Weight. The weight of a soil depends primarily upon two factors—the absolute specific gravity of the individual grains, and the volume of pore space. The latter factor depends chiefly upon the amount of organic matter present.

The average specific gravity of the minerals which make up the great bulk of soil is 2.65. The "volume weight" or "apparent specific gravity" of soils is, however, much less than this, for here we are comparing the weight of the natural soil in place with an equal volume of water, not taking into consideration the pore space (occupied by air), which composes from 40 to 50% of the entire soil volume. It is the "apparent specific gravity" and not the absolute specific gravity of a soil which is of practical consequence to the agriculturist, for it is upon this basis that all fertilizing materials and other soil amendments are added. For instance, a chemical analysis shows that a given soil is in need of lime to correct existing acidity, and the correct amount of lime to apply is wanted when the analysis shows that 0.35% of lime carbonate is required to correct this condition. An apparent specific gravity determination shows that the soil in question weighs 3,000,000 pounds per acre-foot. 3,000,000 lbs. × .0035 = 10,500 lbs., or 5¼ tons is the amount of lime carbonate to apply to correct the acidity present in an acre of this land to a depth of one foot.

A cubic foot of water weighs 62½ pounds; a similar volume of an arable soil usually weighs more except in the case of peaty lands or soils of very high organic matter content. The following table shows the apparent specific gravity, the weight in pounds per cubic foot, and the weight per acre-foot (an acre of land one foot deep) of the common types of cultivated soils, as found in the United States:

Weights of Different Soil Types.*

	Apparent specific gravity.	Weight per cu. ft.—Lbs.	Weight per acre-foot Lbs.
Pure sand	1.76	110	4,800,000
Medium sandy soil	1.54	96	4,200,000
Fine sandy soil	1.48	93	4,080,000
Sandy loam	1.30	81	3,550,000
Fine sandy loam	1.32	82.5	3,590,000
Silt loam	1.24	77.5	3,400,000
Clay loam	1.22	76	3,330,000
Clay	1.17	72.6	3,180,000
Heavy pipe clay	.93	58	2,540,000
Peat	.64	40	1,742,400

We thus see that, as the sizes of the individual soil particles decrease, the absolute weight decreases also. In practice, soils are often spoken of as "light" and "heavy," but these terms refer, not to the *weight* of the soils, but to their "working" qualities.

Several apparent specific gravity determinations have been made by the writer on certain of the leading soil types of these Islands, which would be classed as fine sandy loam and silty clay loam soils. The results have always been lower than figures obtained for similar soil types on the mainland. In other words, a clay loam here on the Hawaiian Islands weighs less when equal volumes are compared than does a similar soil type in the States. Two explanations offer themselves: First, the plantation soils of these Islands are, almost without exception, higher in decomposing organic matter than are similar soil types on the mainland. Second, while the average soils in the States contain from 80 to 90% of silica and about 5% oxide of iron, the Hawaiian soils as a rule contain less than 15% of silica and over 50% of iron and aluminum figured as the oxide. The specific gravity of quartz sand is high, while its tendency to pack together is great. On the other hand, the oxides of iron and aluminum and their attendant hydration products, as they exist in Hawaiian soils, are porous and fluffy and present an immense internal surface, with correspondingly greater pore space. The result is that the apparent specific gravities of our Hawaiian plantation soils vary from 0.97 to 1.25, with an average of about 1.1. An acre-foot of our soil thus weighs very close to 3,000,000 pounds, and it is this figure which is used in the several computations which appear subsequently in this Bulletin.

Texture and Structure. The texture of a soil has to do with the *size* of the individual soil grains, while structure is a term used to denote the ***arrangement*** of the soil particles independently of their size.

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* "Soils," by Lyon and Fippin, p. 96.

The size of soil particles varies from that of coarse gravel and sand down to that of very fine clay, and it is the object of a mechanical analysis to divide a soil into these several fractions. In an analysis of this kind seven fractions or degrees of size are ordinarily made. These are:

Gravel;	**particles greater than**	**.05**	**inch in diameter.**		
Coarse sand;	**particles from**	**.05**	**to**	**.02**	**of an inch in diameter.**
Medium sand;	" "	**.02**	"	**.01**	" " " " "
Fine sand;	" "	**.01**	"	**.004**	" " " " "
Very fine sand;	" "	**.004**	"	**.002**	" " " " "
Silt;	" "	**.002**	"	**.0002**	" " " " "
Clay;	" "	**.002**	"	**and less in diameter.**	

The relative proportions of these various-sized particles, together with the amounts of organic matter present, determine the physical properties of any soil and form the basis of soil classification, viz: sands, silty loams, clay loams, etc.

The number of particles per gram varies with its texture, from about 3 billion for sandy soils to over 20 billion for the heavier clay loams.

Structure is governed as much by the shape of the particles as by their size, and this is determined more or less by the minerals from whence these particles were originally derived. Quartz particles are usually irregularly round with sharp corners. Mica grains are flat, and so on. Structure has an important bearing on a soil's water-holding capacity. This will be discussed later.

Temperature. The temperature of a soil regulates, to a considerable extent, the rate of plant growth, and is dependent upon the following factors: heat supply, color of soil, altitude, air currents, water content of soil, and the amounts of organic matter in the soil which are actively undergoing decomposition.

The soil's most important source of heat is, of course, the sun, although some heat is derived from the warm interior of the earth and some is brought to the earth by rain water. The oxidation (decay) or slow combustion of all forms of organic matter in soils liberates heat and may cause a measurable rise in its temperature. This is often seen in the "heating" of piles of manure or straw.

Dark-colored soils absorb heat more rapidly and lose it less rapidly than do light-colored soils, other conditions being equal. For this reason darker soils are usually earlier and warmer in the spring, where optimum moisture conditions prevail, although the altitude, the slope of the soil toward or away from the sun, and air currents all tend to modify conditions.

The dominating factor in determining soil temperature, however, is water. This is due to the high specific heat of water and to the large amount of heat absorbed from a soil during its evaporation. For this reason "a wet soil is a cold soil." I will not enlarge upon this brief statement. This should furnish sufficient argument for drainage where necessary and for care in irrigation.

A discussion of the moisture relations of soils will be found in Chapter III.

Absorption Phenomena. The last to be taken up, and certainly the least understood, of the several physical properties of soils are their powers of absorption. When a weak aqueous solution of any soluble salt (except nitrates) is poured through a layer of soil and afterwards analyzed, we find that a considerable portion of the salt originally added has vanished. The same also holds for most gases, as well as for certain dyes in solution. This phenomenon is termed absorption or fixation, and is due chiefly to surface tension exerted by the soil's colloidal fraction. The dissolved salts may be changed chemically, but the dyes and gases are not.

Just a few words concerning the properties of colloids. A colloid is a material which, when dissolved or suspended in a very finely-divided form in a solution (usually water), will not pass through certain semi-permeable membranes; a crystalline substance (as sodium nitrate, common salt, etc.), on the other hand, passes readily through these membranes. At present, colloidal solutions are considered to be made up of very minute particles in suspension. Occasionally these particles are far too small to cause the solution to appear turbid, but usually a slight opalescence or turbidity exists, as when true clay (which is a typical colloid) is shaken up in water. These tiny particles are known to carry charges of electricity, some positive charges, others negative charges. Most of the soil colloids carry a negative charge.

A number of substances, such as metallic oxides, are precipitated from a solution of their soluble salts as amorphous solids. These solids frequently contain so much of the solvent from which precipitation takes place that they have a jelly-like consistency, and consequently the term "gel" has been applied to them. When these gels are formed in an aqueous solution and the liquid held in combination with them is water, they are termed "hydrogels." By proper treatment it is possible to cause these gels to redistribute or suspend themselves throughout the liquid from which they were originally precipitated. Such a resuspension of the precipitate in many cases has been found to consist of minute particles of the gel. Where this is the case the opalescent liquid thus formed is termed a sol. Where the solvent used is water, such a suspension is termed a hydrosol.

Colloidal solutions are further distinguished from true solutions by the following properties. They exert little or no effect on the freezing point, vapor tension and vapor pressure of the solution. Heat and the addition of electrolytes usually coagulate and precipitate the colloids, whereas, unless the reagent added is a true precipitant, this is not the case in a true solution.

Now, these colloidal particles, when suspended in a solution, as the soil water, still possess these peculiar properties, probably the most important of which is their ability to withdraw or "adsorb" certain soluble salts and dyes from their solutions. These salts or dyes are simply held to the surface of the colloidal particles, so far as we know, by the force of surface attraction or surface tension, but they are held so tenaciously that simply shaking a few minutes with water will not redissolve or dislodge them. More vigorous treatment, as shaking two or three hours in water, or using weak acids, affect their re-solution. The plant roots also are able to dislodge and use certain of the salts so held. In all probability the retention of many of the plant food elements in the soil is brought about to no small degree by the absorptive power of certain of these colloids.

The soil's colloidal fraction is chiefly made up of organic colloids, formed during the decomposition of plant and animal tissues, silicic acid, hydrated silicates or zeolites and the hydrated oxides of iron and aluminum (especially the latter in Hawaiian soils*).

CHEMICAL PROPERTIES OF SOILS.

Of the eighty-odd elements, above recounted, ten and *only ten* are absolutely essential to the growth of plants. These are carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulphur, calcium, magnesium and iron. The first three are obtained by the plant from water and from the CO_2 present in the atmosphere. The others the plant secures from the soil, and must (with the exception of nitrogen in the case of legumes) be soluble in the soil water in order to be absorbed by the roots.

Other elements often present in plant tissues, but which experiments have shown to be unnecessary for normal growth, are silicon, sodium, aluminum, chlorine and manganese.

The abundant elements (carbon, hydrogen and oxygen) constitute over 95% by weight of all plants. Among the other seven elements are found the deficiencies which limit crop production.

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* See Animal Report for 1915 of the Hawaii Agr. Exp. Sta., pp. 36-37.

These limiting elements are usually nitrogen, phosphorus, potassium and occasionally calcium and sulphur.

In soils the elements exist in two general classes of compounds —the mineral or inorganic class, and the humus or organic class. As has been previously stated, the former is derived directly from the rocks which originally composed the earth's solid crust, while the latter has its origin in vegetable and animal matter.

When rocks are converted into soil the mineral elements of plant food undergo definite chemical changes with the final formation of certain stable compounds. The following table shows the important elements and their different combinations commonly present in arable soils:

Principal Inorganic Chemical Compounds in Soils.

Name of Element.	Forms of Combination.
Calcium, Magnesium	Carbonate and bicarbonate, sulfate, silicate, phosphate, nitrate.
Sodium, Potassium	Carbonate, sulfate, silicate, phosphate, nitrate, chloride.
Iron, Aluminum, Manganese	Oxide, hydroxide, hydrated oxides, phosphate, silicate.

The availabilities of these plant food mineral elements are determined by the relative percentages of their more soluble compounds (nitrates, chlorides, sulfates and bicarbonates), and also by the amounts of soil organic matter undergoing active decomposition.

The second, or organic, class of soil compounds is made up of decomposing plant and animal remains (chiefly carbon, hydrogen, oxygen and nitrogen). This, when so far decayed as to have lost its original structure, we term humus. Humus is not only the sole source of natural soil nitrogen, but it contributes to a soil's productiveness in other ways. Its presence renders the soil more porous, thus enhancing aeration, as well as increasing its absorptive capacity for water. It prevents the hardening and baking of surface soils so often noted in lands poor in this constituent. From the bacterial processes of decay and oxidation the soil's organic matter furnishes carbon dioxide and other substances of an acid nature which, dissolved in the soil water, render more available the mineral elements of plant food; and finally, by its own decomposition and oxidation, humus supplies nitrogen in its most available form (nitrates).

Organic matter, from which humus results, is best supplied to soils: first, by green manuring and crop residues (turning under green, growing crops, or other vegetable matter as straw, stubble. trash, etc.; second, by pasturing animals on the land; third, by direct applications of farm manure.

BIOLOGICAL PROPERTIES OF SOILS.

Rational views on soil fertility have greatly changed during the past half century. The science of bacteriology was in its infancy thirty years ago, and, with its rapid growth, our ideas of agriculture and soil science have broadened and expanded. Until comparatively recent times the soil has been regarded as being composed of dead vegetable and mineral matter, the changes occurring therein, as decay and putrefaction, being ascribed to purely chemical causes. Modern research has disproved and nullified many of these older conceptions. We now know that all arable soils literally teem with unseen life and that these minute living organisms are directly responsible for organic decomposition. The soil is not simply a dead mass of matter; it is dynamic. The more life it harbors, the more fertile it becomes. This micro-organic life consists chiefly of bacteria, molds, yeasts, algae and protozoa. From the standpoint of soil fertility, the most important of these are the several species of beneficial soil bacteria, although certain of the molds and algae are probably of cursory service.

Just as with the higher plants, which are more familiar to us, there are certain factors that affect the number of bacteria in a soil. Among the more important of these may be mentioned moisture, air, organic matter, mineral foods, acidity or alkalinity, toxic bodies and temperature. As a rule sandy soils contain the fewest micro-organisms, because of deficiency of organic matter and poor water-holding power. However, if such soils are plowed deeply and a liberal amount of green material is thoroughly incorporated, the germ content may be increased considerably. An ordinary sandy soil will often contain less than 100,000 bacteria per gram (one twenty-eighth of an ounce), but after some attention has been given to its cultivation, the count may increase to several millions per gram.

In rich loam soils the numbers range from 1,000,000 to several millions, and even into the billions, due to the high organic content which favors bacterial growth.

In the heavy, compact clay soils, such as typical adobe, the germ count is considerably less, owing both to poor aeration and to absence of organic matter.

Under artificial conditions, such as are offered in a greenhouse, where the moisture, temperature, and food supply are especially favorable, it is not uncommon to find numbers ranging around 100,000,000 per gram. The same is true of soil from sewage farms and of soil which has been partially sterilized either by disinfectants or heat in order to destroy certain animal forms* that have been shown to feed upon bacteria. On the whole, it may be said that micro-organisms are most abundant in the soils which are in the highest state of cultivation, and as a rule those soil conditions which are favorable to the growth of the higher plants are also well suited to the development of bacteria.

Bacteria are most numerous in the first seven to eight inches of an arable soil; the germicidal action of the sunshine and the drying at the very surface reduce the numbers there somewhat. Below sixteen inches the count falls off very rapidly, until at three feet, in rainfall sections, the soil is nearly sterile. The texture of the soil, however, makes considerable difference to the lower limit, since with a more open, loose structure, organisms are very apt to find their way to the lower levels. In irrigated regions we know that bacteria frequently occur at depths greater than three feet, for it is not uncommon to find nodules on alfalfa roots, produced by bacteria, eleven or twelve feet below the surface. Other bacteria have been found as deep as eight or ten feet in open soils where the drainage is good and where alfalfa roots have penetrated the earth to considerable depths. † They have undoubtedly been carried down from the surface with the irrigating water and have followed the paths of the alfalfa roots to the lower regions. In the more compact soils we find the lower limit of microbial activity much nearer the surface, since the conditions for aeration are poorer and the filtering action of the finely-divided soil tends to prevent a very extensive penetration even under a head of irrigating water.

All science is based upon one of the great natural laws which we term "The Indestructibility of Matter." We know that there is as much of each and every chemical element on our earth today as existed one million years ago—no more, no less (radioactive elements excepted), but not all of these elements are today in the same forms of chemical combination which they were in then, nor, for that matter, as was the case an hour ago. Of the eighty-odd elements only the ten essential plant food elements are subject to definite, progressive cycles of transformation. At one or more points in each of these cycles the soil bacteria have an indispensable part to play. For the sake of convenience in study, the soil bacteria are divided into six great physiological groups, depending upon their functions within the soil. They are as follows:

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* I refer more especially to the instructive work (extending over the past six years) of Russel and his co-workers in England, on the biological effects of partial and complete sterilization of soils.

† See "The Distribution and Activities of Bacteria in Soils of the Arid Region," by C. B. Lipman, University of Calif., pub. in Agr. Sciences, Vol. I, No. 1, pp. 1-20.

1. The Cellulose-destroying Bacteria.
2. The Ammonifying Bacteria.
3. The Nitrifying Bacteria.
4. The Denitrifying Bacteria.
5. The Nitrogen-fixing Bacteria.
6. The Mineral-transforming Bacteria.

We will discuss these six groups separately.

The Cellulose-destroying Bacteria. These bacteria are concerned with the carbon, hydrogen and oxygen locked up in dead plant tissue. The cell walls of plants are made up almost exclusively of cellulose, which is a very inert substance. It is very resistant to solution or hydrolysis. For this reason much of manure is cellulose. Enormous quantities of carbon are locked up each year by the growing trees and plants, and were there no agents to liberate it as CO_2 from dead organic matter, it has been calculated that all of the CO_2 now in the atmosphere and that set free normally each year by combustion and respiration would be used up by growing vegetation within less than 70 years. We know that animal respiration and combustion supplies about one-tenth of the CO_2 in the air, whereas bacterial decomposition supplies the other nine-tenths.

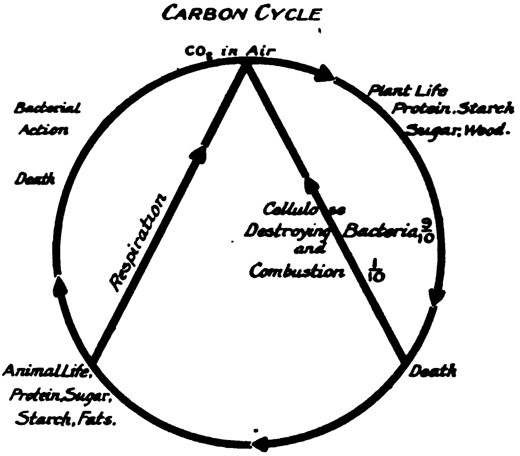

Fig. 1.

Careful experiments have shown that over 12,000 lbs. of CO_2 are given off each year from an acre of fertile soil, and that it is all brought about by the destruction of cellulose in that soil by the aerobic and anaerobic cellulose-destroying bacteria. These organisms accomplish this feat by the excretion of the enzyme cytase, which has the power of breaking up the complex cellulose molecule into carbon dioxide and water. These organisms also decompose the analogues of cellulose as the starches, sugars and woody fibers, with similar results.

I will now explain the Carbon Cycle as shown in Fig. 1.

Let us start with the carbon in combination with oxygen as carbon dioxide. In this form it is a gas and makes up about .04% by volume of the atmosphere. Going down the circle to the right as the arrows point we see the carbon dioxide (CO_2) taken up by means of the chlorophyll within the leaves of plants and changed into the starches, sugars and celluloses of the living plant tissues (photosynthesis). The plant dies. The cellulose-destroying bacteria now come into play. Due to their activities the dead carbonaceous matter is fermented, the CO_2 being again returned to the atmosphere. Some of the wood is burned, thus returning a small fraction of the CO_2 to the atmosphere, and some of the vegetable matter is eaten by animals, which, in respiration, give off CO_2; manure is produced which contains carbon compounds which are decomposed by the cellulose-destroying bacteria, and finally the animal dies and the starches and sugars within its body are eventually destroyed by the same organisms. All of these processes are going on every moment all around us day and night, and yet such an exact equilibrium is continuously maintained that the amount of CO_2 in our atmosphere varies but the smallest fraction of one per cent.

Bacteria and Soil Nitrogen. We will now take up the four great families of bacteria which are responsible for the fortunes of soil nitrogen, and which numerically constitute over 80% of the soil's bacterial flora. There are over 70 million pounds of free nitrogen in the air over every acre of land. Nitrogen is, however, the limiting element of crop production in most agricultural soils. There are several reasons for this: 1st. Organic matter or humus is the chief primary source of this important element, and it is often lacking in sufficient amounts. 2nd. Nitrates and ammonia, formed from this organic matter by bacterial agencies, are the only two forms of nitrogen which have been actually proven to be of direct use to plants, and these are readily lost; the nitrates by leaching, and the ammonia, being a gas considerably lighter than air, by volitization. The river Rhine daily discharges 220 tons of sodium nitrate into the ocean, while the Nile discharges 1,100 tons per day. The value of nitrogen lost in sewage in Great Britain each year, according to Sir Wm. Crookes, is 76,000 pounds sterling, while a similar figure for the United States is over 8 million dollars. 3rd. Humus is often lost in arid regions by a purely chemical oxidation or slow burning. 4th. In poorly aerated or water-logged soils, the denitrifying bacteria (which will be mentioned later) liberate much nitrogen as ammonia, the oxides of nitrogen, and as free nitrogen gas.

Combined nitrogen costs from 15 to 20 cents per pound and is often added to the soil in stable manure, green manure, dried blood, tankage, cotton seed meal, etc. The approximate pounds of nitrogen per ton of each are given below:

	Lbs. per Ton.
Barnyard manure	10–15
Alfalfa hay (green)	15
Red Clover (green)	10–12
Dried blood	260
Tankage	160
Cotton seed meal	100

In these materials the nitrogen is entirely in the form of protein, which, before it can be used by growing plants, must be changed to ammonia and nitrate-nitrogen by the soil's bacteria.

Ammonification is the name applied to the first step in this transformation, and may be defined as the breaking down or decomposition of complex nitrogenous organic substances, usually protein, by the soil's bacteria and molds, one of the final end products of which is ammonia gas. The ammonifiers are the largest single family of soil bacteria, both in point of numbers and also of species. In acid soils molds are in large part responsible for ammonia production.

The ammonifiers, similarly to the cellulose destroyers, are made up of two classes—the aerobic or decay bacteria, whose final end products are CO_2, water, ammonia, sulphates and carbonates of the minerals; and the anaerobic, or putrefactive bacteria, which produce ill-smelling products of higher molecular weight, as indol, skatol, amino acids, methane, hydrogen sulphide and some ammonia. The mineral elements here usually remain as complex salts of the higher organic acids. Both processes involve ammonia production, but far more is produced from a given amount of nitrogenous material by decay than by putrefaction. Both forms of ammonification are brought about by the peptonizing and proteolitic enzymes which these bacteria secrete, and are thus true fermentations. As soon as ammonia is produced in the soil it combines with the CO_2 saturated water to form ammonium carbonate. We know that this compound is an available source of nitrogen for some plants, as rice and possibly other grains, but most crops are unable to so use ammonia nitrogen. It is here that the nitrifiers step in and oxidize the nitrogen in the ammonium carbonate to nitric acid, or nitrates, the final end product, which all plants can use directly as food.

Nitrification is brought about in two distinct stages and by two entirely different species of bacteria. The Nitrosomonas, or nitrite bacteria, oxidize the ammonium carbonate to nitrous acid and nitrites, but can go no further. The Nitrobacter here take up the work and complete the oxidation to nitric acid and nitrates. Nitrification may properly be defined as that process by which ammonium carbonate is oxidized to nitrate by the action of the nitrifying bacteria. This is distinctly an aerobic process, an excess of oxygen being required.

Denitrification is the reverse of nitrification. The denitrifying bacteria reduce the nitrate, either applied to the land as such or formed in situ, to ammonia, the lower oxides of nitrogen, or in some cases to free nitrogen gas. In other words, they undo the work of the nitrifying bacteria and are inimical to a soil's fertility. It is indeed fortunate that these bacteria are chiefly species which prefer anaerobic conditions, as these are seldom found except in poorly-aerated, water-logged, heavy soils. We thus feel confident in saying that large losses of nitrate nitrogen do not occur through denitrification in most properly-tilled, arable fields.

We now come to the two large groups of nitrogen-fixing bacteria. Up to this time we have discussed the *transformation* of nitrogen compounds only, and we have seen that there are many *losses* of nitrogen through leaching, volatilization and denitrification. Were there no processes by which these losses of combined nitrogen might be made good, all nitrogenous compounds would in time become dissipated. But there are two classes of soil bacteria which have the power of taking up the gaseous nitrogen from the air and building it into protein within their own body cells. These two kinds of nitrogen-gathering bacteria are, first, those which live in the soil itself independently of the presence of growing plants; and, second, the bacteria which live in the nodules on the roots of leguminous plants. Those in the first class are known as non-symbiotic, while those in the second class are termed symbiotic nitrogen-fixing bacteria.

There are two species of these free-living nitrogen-fixers which do not live on the roots of legumes. The anaerobic forms, whose chief member is *Clos. pasteurianum,* discovered in 1893 by Winogradski, live principally in the lower strata of the soil (between the second and fifth feet), where the supply of oxygen is very limited. It is the aerobic forms, the *Azotobacter* species, living chiefly in the surface 6 or 8 inches, which are the most important of these two classes. The first member of this interesting group, *Azotobacter chroococcum*, was discovered by Beijerinck in 1901. Since then five or six other varieties have been added. These aerobic forms fix from eight to twelve times as much nitrogen per unit of carbohydrate (which they use as food) as do the anaerobic species.

There are several soil conditions which must be correct for any considerable fixation to take place. An abundance of decomposing organic matter is essential, for carbon is the source of energy for this class of bacteria. Without it there would be no fixation. An alkaline reaction of the soil, thorough aeration, and proper temperature and moisture conditions are other desirable circumstances. One of the beneficial effects of fallowing land is due to these non-symbiotic nitrogen-fixers. The following table shows in pounds per acre per year, the amounts of nitrogen which simply fallowing the land will add. The first two figures come from the Rothamsted Experimental Fields in England:

100 lbs. N. per acre,	Broadbalk Field.
25 lbs. N. per acre,	Geescroft Field.
175 lbs. N. per acre,	Minnesota Experiment Station.

The symbiotic nitrogen-fixing bacteria are those which live in the nodules found on the roots of leguminous plants. These bacteria obtain their carbohydrate food from the growing plant, while the plants in return acquire their soluble nitrogen from the bacteria. These have previously procured this nitrogen from the outside soil air, and transformed it into a soluble protein form available to the growing plant.

It has been known for centuries that growing legumes greatly improves the land. Ancient Roman writings tell us that growing plants of the pod family greatly helps a soil's fertility for other crops. But until Hellriegel and Wilfarth's classical experiments in 1888, no one knew just why this was true. These careful and able investigators showed beyond a doubt that legumes themselves could fix no free atmosphere nitrogen without the presence of nodules on their roots, and that these nodules resulted from bacterial activity entirely aside from the plant itself, and further, that these swellings or nodules were filled with living bacteria which alone were the agents of nitrogen fixation. Beijerinck, a year later, isolated the nodule organism in pure culture and named it *B. radicicola*. A vast amount of scientific work has been done along this line. We are now sure of eight or nine strains of *B. radicicola,* all of which are dissimilar and each able to infect and produce nodules on only a few different kinds of legumes. More plainly stated, each legume has its own specialized strain of *B. radicicola,* which alone is able to produce nodules on its roots. Practically all the nodules are formed within the surface five or six inches. Space does not permit of the discussion here of soil inoculation.

There are certain conditions of the soil which are essential to the successful growth of legume cover crops. The more important are: 1st. A neutral or slightly alkaline reaction of the soil, for the bacteria which enter the roots of the legumes, produce nodules, and eventually fix the free nitrogen gas, cannot live and properly function in an acid soil. (Lupines are apparently an exception, as they prefer a neutral or slightly acid soil.) 2nd. The fixation of nitrogen is distinctly an aerobic process. The soil must thus preferably be light in texture and well drained. 3rd. The proper strain of *B. radicicola* must be present to thoroughly inoculate the roots of the legume chosen for the cover crop.

The nitrogen in green legumes is more available than that from other green plants, as it has been shown that the ammonifying and nitrifying bacteria are more easily able to transform it into nitrates.

The amounts of nitrogen fixed per acre by an average crop of:

	Per Acre.	Experiment Station Where Tested.
Crimson clover	205 lbs.	New Jersey
Crimson clover	188 "	Delaware
Velvet beans	213 "	Alabama
Velvet beans	172 "	Louisiana
Velvet beans	141 "	Florida
Alfalfa	160 "	Illinois (last cutting only plowed under)

An average of all legumes from 16 State Experiment Stations where tests have been made gave 122 lbs. of nitrogen added per acre per crop.

We thus see that, while there are many losses of nitrogen from soils, there are always present agents which, where conditions are favorable, provide for the maintenance of the proper balance of this most important of all the plant food elements.

I will now explain the Nitrogen Cycle as shown in Fig. 2. Let us start with the nitrogen in the protein of the living plant, as shown at the top of the circle, and follow the arrows. The plant dies and is either taken in as food by animals or returns again to the soil. If the former, it is converted into animal protein, the

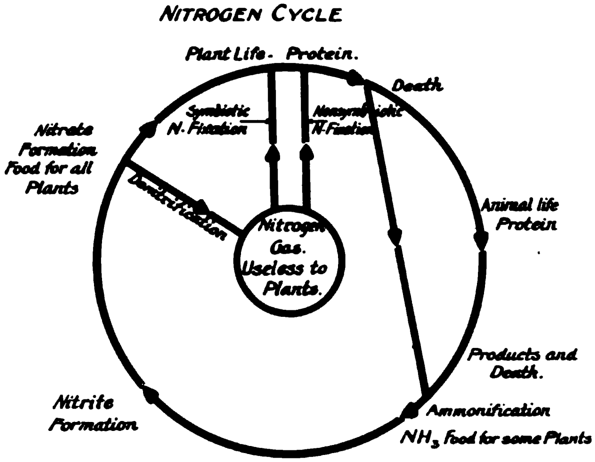

Fig. 2.

waste being given off as urine or fecal material. The latter returns eventually to the soil, as does the body of the animal itself when death overtakes it. The first bacterial step in the Nitrogen Cycle is the breaking down (the putrefaction and decay) of these dead plant and animal remains in the soil, which we term Ammonification. The nitrifying organisms now come into play and change the ammonia nitrogen, which the ammonifying organisms have produced, first to nitrites and finally to nitrates, in which form the nitrogen can be taken up and used over again by the higher plants. This would complete the cycle, as we have now returned to our starting point, were it not that, due chiefly to dentrification, large amounts of nitrate nitrogen each year are reduced to the free nitrogen gas of the atmosphere, which is absolutely worthless as a source of nitrogen for the higher plants. Here the great families of nitrogen-fixing bacteria step in and, by working as above explained, restore the losses and keep in proper equilibrium this great Nitrogen Cycle.

Relation of Bacteria to Minerals. There are four ways in which acids are formed in soils:

1. The cellulose-destroying and ammonifying bacteria produce organic acids.
2. The nitrifying bacteria produce nitric acid.
3. The CO_2 saturated water gives us carbonic acid.
4. The sulphur oxidizing bacteria, Beggiatoa and Thiothrix, produce sulphuric acid from the hydrogen sulphide given off by

the ammonifying bacteria upon the decomposition of the protein molecule.

These acids acting on the potash, lime, magnesium and phosphorus-bearing minerals slowly render them soluble and available to the growing plants. The potassium is usually changed to the carbonate, nitrate, or sulphate; the lime and magnesium to the nitrate and bicarbonate forms, while the phosphorous is taken up by the plant as the acid phosphate of one of the bases.

It is thought that the iron bacteria, chiefly the Crenothrix species, reduce ferric oxide and ferric hydroxide, and that this element is finally taken up by the plant as ferrous bicarbonate, although some authorities argue for the sulphate and phosphate forms.

Each of the mineral plant foods thus has its cycle of transformations which, while much simpler than that of nitrogen, is nevertheless as important and must not be overlooked.

There are certain general soil conditions which greatly favor the activities of all of the beneficial soil bacteria, most important of which may be mentioned the following:

1st. The reaction of the soil should be neutral or slightly alkaline. It has been shown by many experiments that each class of the helpful soil bacteria is greatly enhanced by such a condition. This may be accomplished by the use of lime in some form.

2nd. All of the beneficial bacteria are aerobic and demand an excess of oxygen. This may be given them by deep plowing and proper cultivation. To this may be added artificial drainage where soils are low-lying, heavy and water-logged.

3rd. Sufficient organic matter should be at hand to furnish the proper food materials and sources of energy for this invisible army.

Such improvements in methods for the bacterial examination of soils have been made in the past few years that at present we may study with a surprising degree of accuracy the relation between bacterial activities and crops produced.* Thus the ammonifying power, the nitrifying power and the nitrogen-fixing power of soils as today determined, together with certain chemical determinations, give us a very good indication as to a soil's relative fertility.

CHAPTER II.

THE SOILS OF THE ISLANDS IN GENERAL, AND THOSE OF HAWAII IN PARTICULAR.

The Hawaiian Islands represent the higher summits of a chain of mountains, mainly submarine, which extend for about 1800 miles in a general northwesterly direction. Soundings have shown the existence of many other mountains in addition to those whose peaks project above sea level. The ocean bottom from which these mountains rise is over 20,000 feet below the surface. All of the islands of this archipelago are of volcanic origin; the rocks, therefore, with the exception of coral deposits, are basaltic lavas. A discussion of Hawaiian rocks will not be attempted, as this information may readily be obtained from standard works on geology. Suffice it to say that the more important minerals which go to make up the lavas are plagioclase, augite, olivine and magnetite.[†] Potash feldspars occur in considerable quantity as elements in the plagioclase, as do albite, oligoclase and labradorite. Free silica is present in very few Hawaiian lavas, but many are similar to the quartz basalts of other regions. Chemically, Hawaiian rocks differ very little from the basalts of other volcanic regions on the mainland. The following averages of ultimate analyses made at this Station by Maxwell in 1898 prove this point. Typical samples of lava rock were obtained from each of the islands of Hawaii, Maui, Kauai and Oahu and their average composition compared with analyses of American basalts as made by Clarke of the U. S. Geological Survey.

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* See "Bacterial Activities and Crop Production," by P. E. Brown, Iowa Expt. Sta. Research Bul. No. 25.

Average Composition of Hawaiian and American Basaltic Lavas.[§]

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
Hawaiian basalts....	47.90	18.23	13.36	8.99	6.05	2.20	1.50
American " ...	49.15	15.66	9.50	8.29	7.90	2.84	1.90

This average composition for Hawaiian basalts is very close to that given by Cross of the U. S. Geological Survey in his bulletin, "Lavas of Hawaii and Their Relations."

Being of very similar original petrological composition, one might suppose that the soils of the various islands would be more or less identical. This, however, is not the case. The differences are due directly to two factors—variance in geological age, and rainfall.

Most geologists agree that the Hawaiian Islands were formed more or less successively from the northwest to the southeast. The Leeward Islands and Kauai are thus much older, geologically speaking, than are Maui and Hawaii. It is certainly a fact that erosion has proceeded further on Kauai and on Oahu than on the Island of Hawaii, which is thought to be the most recent.

[†] See "Lavas of Hawaii and Their Relations," by W. Cross, Professional Paper 88, U. S. Geo. Survey.

[§] See "Lavas and Soils of the Hawaiian Islands," by W. Maxwell, pub. by H. S. P. A. Expt. Sta., Honolulu, T. H. (1898).

The rainfall varies between wide extremes depending upon location. In certain areas arid conditions prevail while over a large part of the uplands and on windward Hawaii and Maui the rainfall is excessive (between 200 and 300 inches per annum in certain districts).

The resulting soils of the Islands are peculiar soils. The following table, compiled from a variety of authentic sources compares the average chemical composition of mainland soils with those of these Islands. The figures given for American soils represent averaged of 1547 complete analyses, while those given for Hawaiian soils are average of 515 analyses, made both in the laboratories of the Hawaiian Sugar Planters' Experiment Station and in those of the Hawaiian Federal Experiment Station. The analyses were made by the strong acid digestion, or "Agricultural Method."

Comparative Percentage Composition of American and Hawaiian Soils.

	Total SiO_2	Soluble SiO_2	K_2O	Na_2O	CaO	MgO	Mn_3O_4	$FeO + Fe_2O_3$	Al_2O_3	P_2O_5	SO_3	N
American Soils	85.52	6 40	0.40	0.27	0.75	0.68	0.12	3.81	5.15	0.16	0.04	0.18
Hawaiian Soils	32.63	17.59	0.34	0.35	1.30	1.18	0.50	28.02	20.72	0.35	0.32	0.33

The lime-magnesia ratio in Hawaiian soils is often abnormal, in some cases the percentage of magnesia being three to four times that of lime. High percentages of iron and aluminum oxides are the rule. In a majority of the soils these combined oxides constitute approximately one-half of the soil mass, while the total silica content is usually below 25%. As will also be observed, the amounts of *soluble* silica in Hawaiian soils are about three times those for American soils. In many cases very nearly all of the silica is present in soluble forms. In certain localities of poor drainage small amounts of ferrous iron exist.

Hawaiian soils are usually heavy in character, often containing from 35 to 50 percent of particles fine enough to be classed as clay. This fine material is not, however, true clay (hydrated aluminum silicate) but is chiefly hydrated oxide of iron and aluminum together with double silicates of these metals. Another unique property of these soils is their unusually high content of certain of the rarer elements, notably manganese and titanium.

In certain high manganese areas on Oahu and Kauai from 4 to 9% of the oxide (Mn_3O_4) are found while the average for all islands is 0.50%. Of titanium, the general average for the Islands is 2.93%. To quote from Kelley,[*] "The soils of the Kunia section (Oahu) are unusually high in titanium, containing in some instances as much as 35% titanium dioxid (TiO_2), but the titanium is relatively insoluble, and consequently the usual agricultural analysis fails to show the total amounts present." This element is apparently inert toward plant growth.

The table is self explanatory as regards the comparative amounts of the several plant food elements. It may be stated, however, that, although phosphoric acid (P_2O_5) is here abundant, most of it occurs as the comparatively insoluble ferric and aluminic phosphates which are in large part unavailable,[**] rendering phosphate fertilization advisable. The nitrogen, compared with mainland soils, is high, but, due chiefly to poor aeration combined with excessive rainfall in certain localities and to soil acidity, its availability is low.

Notwithstanding the basic character of Hawaiian soils, large areas of very acid soils are found in the sections of heavy rainfall. Ten to fifteen tons of lime carbonate per acre-foot are often indicated by the Veitch Method. On the other hand, near sea level, considerable areas of coral lands have been formed which contain from 60 to 90% of lime carbonate.

Biologically speaking, the soils of the Hawaiian Islands differ to a surprising degree. In certain soil areas ammonification, nitrification and nitrogen fixation are very low (the last two practically nil), while in other well cultivated and well fertilized fields the absolute reverse is true. While no hard and fast rule can be laid down, it may be generally stated that, other conditions being equal, bacterial efficiency gradually decreases as altitude increases. This is due in all probability to lower temperature and to excessive moisture conditions.

With this very brief discussion of the soils of the entire Group, let us take up, in some detail, the soil types found on the Island of Hawaii.[†]

Hawaii is the largest and the most recent of the entire archapeligo. It has the highest mountains, and by far the greatest changes in climate, including rainfall. This latter varies from a few inches in the South Kona and Kau districts to nearly 300 inches (per annum) in the Hilo section, and mauka.[††]

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[*] "The Soils of the Hawaiian Islands," Bul. 40, Hawaii Agr. Exp. Sta.

[**] See "Phosphate Fertilizers for Hawaiian Soils," by W. T. McGeorge, Hawaii (U. S) Agr. Exp. Sta. Bul. No. 41.

[†] It should be understood at the outset that the studies reported in this Bulletin are concerned entirely with the soils of those sections growing sugar cane.

[††] Uplands; about 600 feet above sea level and higher.

There are four distinct soil districts on the Island of Hawaii within each of which the soils are quite similar in character, but which differ considerably, the one from the other. (See frontispiece map.) These are the Hilo-Puna District, the Hilo and Hamakua Coast District, the Kohala District and the Kau District. The chief primary cause for the soil differences noted is doubtless to be found in the rainfall which is excessive in the first section indicated, less in the second and third, and least in the fourth. Physically, the soils range from almost a vegetable mold in the mauka fields of the Olaa Sugar Company and the Waiakea Mill Company, through the fine sandy and silty loams as found at Pahala (Kau) to the heavier clay and silty clay loams as encountered along the Hamakua and Hilo Coasts and in Kohala. Of course these soils gradually merge the one into the other, and, within these several districts, other than the predominating types often exist, yet the general divisions above made hold for a great majority of th soils therein encountered. The average depth of the mauka surface soils (down to a decided change in color) is from 4 to 6 inches, while those near the sea usually run to about twice this depth. The surface soils are always darker in color than the corresponding sub-soils and usually contain several times as much organic matter.

Practically all of the plantations on Hawaii border the sea at their lower level and run back and upward toward the high interior of the Island to altitudes which vary from 1100 to 2500 feet (in Kau). Above these elevations the constant rain and cold weather militate against the profitable production of sugar cane. In collecting the soil samples for this work it has been the writer's object to secure representative samples from the several elevations on each plantation visited. He has, in each case, been advised and assisted in this by either the plantation manager or by one of his overseers. Samples have usually been taken from the highest fields on the plantation, from the middle sections, and from the lower lands bordering the sea.

In collecting these samples, the surface inch of soil was removed and the surface sample drawn with a clean trowel, placed in its properly labeled, heavy canvass bag (which had been previously sterilized), and immediately closed. A hole about 18 to 20 inches square was then dug deep enough to penetrate the sub-soil and a sample taken from the bottom of this hole, care being used not to contaminate this sub-soil sample with soil from above. About eight pounds of soil were taken in each case. In labeling, the letters "A" and "B" refer to surface and sub-soil samples, while the numbers denote locations. Thus soil number "4A" refers to the sample taken at location "4" and is a surface soil. In some cases where solid rock was encountered or where, for other reasons, it was deemed unnecessary to take a sub-soil sample this was omitted. The table which follows shows the different plantations, within the four districts, from whence samples were drawn. The first column gives the laboratory number of the sample, which throughout this bulletin will be used to designate it alone, while the second column shows the plantation.

TABLE I.

Location of Soil Samples.

Hilo-Puna District.

Number. Laboratory	Plantation.
1A—1B	Waiakea Mill Company.
2A	“
3A	“
4A	“
36A—36B	Olaa Sugar Company.
37A—37B	“
38A	“

Hilo and Hamakua Coast District.

5A—5B	Onomea Sugar Company.
6A—6B	“
7A	“
8A—8B	“
23A—23B	Pepeekeo Sugar Company.
24A—24B	“
21A—21B	Kaiwiki Sugar Company.
22A—22B	“
18A—18B	Hamakua Mill Company.
19A	“
20A—20B	“
16A	Honokaa Sugar Company.
17A	“
14A—14B	Pacific Sugar Mill.
15A—15B	“

Kohala District.

25A—25B	Hawi Mill & Plantation Co.
26A—26B	“
27A	“
28A—28B	“
32A	Kohala Sugar Company.
33A	“
34A	“
35A	“
29A—29B	Niulii Mill and Plantation Co.
30A	“
31A—31B	“

Kau District.

9A—9B	Hawaiian Agricultural Co.
10A	"
11A—11B	"
12A—12B	"
13A	"

I will now briefly locate and describe each individual sample drawn.

Hilo-Puna District.

No. 1A and 1B...............Waiakea Mill Company.
Field 35.....................Mauka (elevation 1,100 feet).
Surface soil 5 to 6 inches deep.
Typical forest soil. Very high in organic matter.
In cane for the last 8 years.

No. 2A......................Waiakea Mill Company.
Field 26.....................Middle (elevation 650 feet).
Surface soil 6 to 7 inches down to solid rock.
In cane about 16 years.

No. 3A......................Waiakea Mill Company.
Field 6......................Makai (elevation 100 feet).
Surface soil 8 to 10 inches deep.
Aa formation directly below. Produces best cane on plantation.
In cane about 35 years.

No. 4A......................Waiakea Mill Company.
Field 6......................Makai (elevation 100 feet).
Water down 12 to 18 inches.
Soil heavy and wet over pahoehoe formation.
Poor drainage.
In cane about 35 years.

No. 36A and 36B.............Olaa Sugar Company.
Field P......................Middle (elevation 650 feet).
Surface soil 6 inches deep.
In cane 15 years.

No. 37A and 37B.............Olaa Sugar Company.
Mountain View 4 and 5......Mauka (elevation 1,700 feet).
Surface soil 4 inches deep.
In cane 15 years.

No. 38A.....................Olaa Sugar Company.
Field D..................... Makai (elevation 200 feet).
Surface soil 7 to 9 inches deep.
No sub-soil, aa formation.
In cane 16 years.

Hilo and Hamakua Coast District.

No. 5A and 5B.............Onomea Sugar Company.
Field 7, Onomea section......Mauka (elevation 1,300 feet).
Surface soil 6 inches deep.
In cane about 25 years.

No. 6A and 6B.............. Onomea Sugar Company.
Field 97, Paukaa section......Mauka (elevation 1,350 feet.
Surface soil 6 inches deep.
In cane 14 years.

No. 7A......................Onomea Sugar Company.
Field 34, Expt. plot 6C.......Makai (elevation 275 feet).
Surface soil 18 inches deep.
In cane 22 years.

No. 8A and 8B.............. Onomea Sugar Company.
Field 25, Papaikou section....Makai (elevation 175 fet.)
This sample was taken near the cliff bordering the sea which is over 100 feet above high water mark.
Surface soil 10 inches deep.
In cane 30 years.

No. 23A and 23B.............Pepeekeo Sugar Company.
Robertson Field............. Makai (elevation 400 feet).
This field has been limed several times and has had trash turned under for the past 12 years.
Surface soil 10 inches deep.
This is a very old field.

No. 24A and 24B............Pepeekeo Sugar Company.
This sample was drawn from the center of the highest field on the plantation.
Elevation about 1,500 feet.
It has been limed once and had trash turned under for the past 8 years.
Surface soil 6 inches deep.
In cane 10 years.

No. 21A and 21B............Kaiwiki Sugar Company.
Field 27....................Mauka (elevation 1,450 feet).
Limed once this past year (8 barrels quick lime per acre.)
Surface soil 6 inches deep.
In cane about 6 years.

No. 22A and 22B............ Kaiwiki Sugar Company.
Field 10.....................Makai (elevation 150 feet).
Limed once six years ago.
Surface soil 10 inches deep.
Very old field.

No. 18A and 18B............Hamakua Mill Company.
Field 17, Opihilala...........Makai (elevation 400 feet).
This field was limed in 1915 and then had a heavy crop of lupins plowed under.
This sample was taken from under a small piece of good Lahaina cane.
Surface soil 12 inches deep, fine appearance.
In cane 35 years.

No. 19A....................Hamakua Mill Company.
Field 24, Manienie...........Middle (elevation 900 feet).
Virgin soil. just cleared of trees; never has grown a crop.
Surface soil deep (over 2 feet).

No. 20A and 20B.............Hamakua Mill Company.
Field 19, Opihila.............Mauka (elevation 2,200 feet).
Sample taken from highest place on plantation.
Limed once and green soiled in 1913. Originally cleared from heavy forest.
Surface soil 5 inches deep.
In cane 12 years.

No. 16A.....................Honokaa Sugar Company.
Field C.....................Mauka (elevaion 1,900 feet).
One of last fields cleared, near homesteads.
In cane about 15 years.
Both surface and sub-soils are very familiar in appearance; about 5 feet deep.

No. 17A.....................Honokaa Sugar Company.
Field 35.....................Makai (elevation 250 feet).
This sample was taken below the mill, not far from the cliff by the sea which here is about 200 feet high.
The soil is very uniform to a depth of about 5 feet where large stones are encountered.
This is a very old field; in cane 30 years or more.

No. 14A and 14B.............Pacific Sugar Mill.
Field 11 and edge of 21...... Mauka (elevation 1,800 feet).
Close to edge of Waipio Gulch.
Surface soil about 6 inches deep; sub-soil very hard and heavy.
In cane 25 years.

No. 15A and 15B.............Pacific Sugar Mill.
Field 5......................Makai (elevation about 600 feet).
Surface soil 10 to 12 inches deep.
In cane 30 years or more.

Kohala District.

No. 25A and 25B.............Hawi Mill and Plantation Company.
Field 25.....................Mauka (elevation 1,500 feet).
Surface soil about 12 inches deep. Sub-soil stony.
Old field; in cane 25 or 30 years.

No. 26A and 26B.............Hawi Mill and Plantation Company.
Field H-13.................. Middle (elevation 450 feet).
New land; first crop now being planted.
Surface soil 18 inches deep.

No. 27A.....................Hawi Mill and Plantation Company.
Field 17.....................Middle (elevation 450 feet).
Surface soil deep.
Very old cane land. This sample taken about 150 yards from No. 26.

No. 28A and 28B.............Hawi Mill and Plantation Company.
Field H-7.................. Makai (elevation 60 feet).
Lowest point on plantation.
Surface soil 12 inches deep.
Very old field.

No. 32A....................Kohala Sugar Company.
Field Halelua 7..............Middle (elevation 320 feet).
Surface soil over 12 inches deep.
Very old field.

No. 33A.....................Kohala Sugar Company.
Field Maulili 7..............Mauka (elevation 1,700 feet).
Down to solid rock, 6 to 7 inches.
Old field. Now planted to D-1135; very poor growth.

No. 34A....................Kohala Sugar Company.
Field Maulili 5..............Middle (elevation 600 feet).
Old field; deep soil.

No. 35A....................Kohala Sugar Company.
Field Ainakea 1.............Makai (elevation 200 feet).
Deep soil.
Old field, newly planted.

No. 29A and 29B............Niulii Mill and Plantation Company.
Ku's Field..................Mauka (elevation 1,100 feet).
Surface soil 6 inches deep.
In cane 30 years.

No. 30A....................Niulii Mill and Plantation Company.
Field mauka Government road and makai Soloman's house.
Makai (elevation about 100 feet).
Soil uniform down to 3 feet. Very deep.
In cane 38 years.

No. 31A and 31B.............Niulii Mill and Plantation Company.
Field just mauka railroad station....................Makai (elevation 100 feet).
Surface soil 12 inches deep.
In cane over 40 years.

Kau District.

No. 9A and 9B...............Hawaiian Agricultural Company.
Middle Stone Field...........Middle (elevation 2,000 feet).
Surface soil 12 inches deep.
Black silt loam soil in fine physical condition.
In cane 30 years.

No. 10A.......... ....Hawaiian Agricultural Company.
Middle Mud Flow Field, near lower edge (elevation 2,200 feet).
Sample taken from surface only as this is a homogenous soil down to a depth of 8 feet.
It would be classed as a stony loam soil.
In cane 15 years.

No. 11A and 11B............Hawaiian Agricultural Company.
Lower Wood Valley Field.....Middle (elevation 2,100 feet).
Surface soil 6 inches deep; fine sandy loam.
In cane 18 years.

No. 12A and 12B............Hawaiian Agricultural Company.
Hionamoa Field..............Mauka (elevation 2,800 feet).
This is the highest field growing cane on Hawaii.
Surface soil very shallow, 3 to 4 inches deep.
In cane off and on for 15 years; at present fallow.

No. 13A....................Hawaiian Agricultural Company.
Palau Field..................Makai (elevation 900 feet).
This is considered the best land on the plantation.
It is a very deep, uniform silt loam soil, transported from above.
In cane for over 40 years.

It will be seen that the different altitudes as well as the several sections of the Island were sampled with care.

The soils on the plantations where no samples were drawn were in almost all cases investigated and found to be very similar, if not identical, with those which had been sampled on neighboring plantations.

In discussing the data which follows, the several districts will, as a rule, be taken up separately.

CHAPTER III.

PHYSICAL SOIL STUDIES.

In Chapter I appeared a brief discussion of the more important physical characteristics of soils. Soil moisture was there intentionally omitted and will here receive its merited attention.

It is universally recognized that a soil's relations to water are of far more importance to the practical agriculturist than are all of its other physical characteristics combined. In fact the moisture coefficients are in reality a summation of all of the other dominant traits, including apparent specific gravity, texture, humus content, colloid content, etc. When it is recalled that over 80% of the weight of most green plants is water the truth of this statement is apparent. (Sugar cane averages about 73% water due to high sugar content of juice.)

Water is especially adapted to its indispensible functions in relation to vegetable life. Careful experiment has demonstrated the following truths: Water, by capillarity, rises higher both in the soil and in the tissues of plants than does any other liquid. Its temperature changes more slowly than does that of any other liquid, thus serving to prevent injuriously rapid temperature changes in plants as well as in soils. Its high heat of fusion also prevents the quick freezing of plant or animal tissues. The large amount of heat required to evaporate water serves to keep plants cool under excessive external temperatures which would otherwise quickly destroy life. To these properties of water should be added its almost universal solvent power, especially for mineral materials. It is true that this power is often slow, but it is nevertheless inevitable. The soil water is thus able to convey to the growing root hairs of plants the necessary foods for their consumption.

Let us now discuss briefly the different conditions in which the soil water may be physically present in an arable soil. It should be understood that soil water is at all times a very complex solution of both minerals and gases. All of the necessary plant food elements are present, usually in very small quantities, together with the gases oxygen, nitrogen and carbon dioxide. Each of the three different kinds (physically) of soil water are the same chemically. They differ only in the *concentration* of these dissolved compounds—especially the mineral elements. Nearly all discussions of soil water are based upon a classification which was early made in the study of this subject and which is both justifiable and sound. Soil moisture is divided into hygroscopic, capillary and gravitational, according as it is tenaceously held in the thin films about the soil particles; held against the force of gravity by surface tension in the capillary pores of the soil; or freely moving under the action of gravity. Unless understood, this classification is unfortunate in that it suggests the existence of the soil water in three different chemical states which is not the case, as above stated. This classification is one of *forces,* not of materials, and all of these forces affect either directly or indirectly all soil water. It might be better to drop the older terminology and consider the water in toto as a unit, and speak not of hydroscopic, capillary and gravitational water, but of the hygroscopic, capillary and gravitational forces reacting upon this water.

Let us take up these forces or, to revert to the older teminology, "kinds" of soil moisture in some detail.

Hygroscopic Water. There are two great forces always operative in nature, adhesion and cohesion. The former may be defined as that force which unites together minute particles, termed molecules, of entirely different chemical substances, while in the latter case the operative force tends to bring together or unite molecules of the same substance. For example, if a marble is dipped into water and withdrawn, it carries with it a thin film of water over its entire surface. This shows that for a certain distance from its surface the marble exerts a stronger pull for the water than the water does for itself. If the marble is dipped into mercury instead of water, it comes out perfectly dry because the mercury in this case has a greater attraction for its own molecules than it does for those of the marble. The former is an example of adhesive force while the latter shows the strong cohesive tendency of mercury. It is the former tendency which interests us in a discussion of hygroscopic soil moisture. Soils artificially dried so as to deprive them of all of their moisture, when exposed to moist air at first absorb water vapor with great avidity. Finally a state of equilibrium is reached for any given temperature and rate of humidity. At this point no more water can be taken up by the soil under experiment. The smaller the individual particles of any soil the more water it will absorb from a saturated atmosphere due to its greater internal surface. It thus follows that sandy soils absorb the smallest amounts, while clay soils and those containing much humus or finely divided ferric hydrate taken up the largest proportion. All field soils when air dry in situ contain certain amounts of hygroscopic water depending upon their texture, structure, organic matter content, temperature and the humidity of the air. As has been proven by Hilgard, the amount of water absorbed by a soil slightly increases in a completely saturated atmosphere, as the temperature rises; at least this is the case up to a temperature of approximately 40° C. We may thus define the "hygroscopic moisture coefficient" of any soil as the maximum percentage of water which it can absorb from a saturated atmosphere at a temperature of 20° C. (68° F.)

As was stated above, these thin films of hygroscopic water are held *very tenaciously* by the solid particles of the soil, and may be considered as the connecting link between the water system and the solid frame-work of the soil. So far as we know, hygroscopic water is absolutely unavailable to plants, although by preventing rapid and undue heating of the surface soil it may be of indirect benefit. Hilgard states that certain desert plants may be able to maintain normal growth on this fraction of the soil's moisture but it remains unproven. It should also be noted that it is within the hygroscopic water films that most of the mineral solvent action primarily occurs.

Capillary Water. We now come to the most important physical form in which soil water exists, for it is entirely from this fraction that most plants draw their necessary supply. This is the liquid water held by capillarity in the pores of the soil against the force of gravity. This water moves either upward, downward or laterally, absolutely independently of the force of gravity until uniformity of surface tension is established; and this is seldom effected in fallow arable soils, and never under a growing crop, for here the plants are continually drawing water from these capillary films. By interchange with the hygroscopic films the capillary water receives the necessary dissolved mineral constituents, thus serving as the vehicle of all plant food absorbed by the growing plant besides supplying moisture to sustain the enormous transpiration by which plants maintain, during the hottest days, a temperature sufficiently low to permit of proper photo-synthesis. The capillary water would soon be exhausted were it not replenished. This is effected by the rising of water by capillarity from the "ground water" or "water table" into the root zone, and the rapidity of this water movement is of prime importance to the thirsty plant. The heavy soils running high in clay are able to raise water to the greatest height (11 feet in some cases), but this rise is often too slow to sustain plant life. The lighter soils, on the other hand, as the sandy soils and loams, can lift water but four or five feet, yet the *quantity* of water so raised will readily meet the demands of the growing crop. We thus see that a heavy soil and a dry climate with low water table are unfavorable conditions for most crop plants.

In most cultivated soils the air spaces constitute from 40 to 50% of their total volume, and this space when filled with water represents the saturation point or its "maximum water-holding capacity." For the best development of plants it has been found that the soil moisture present should not exceed 60% of its "maximum water-holding capacity." This, for most soils, will be found to *closely* approximate the sum of the hygroscopic and the capillary waters, and, as will be seen, leaves about 40% of the pore space to be filled with air. This condition is usually termed the "optimum moisture content" of a given soil. Of course this figure of 60% varies slightly depending upon the soil and the plant, but not greatly.

Gravitational Water. This is that portion of the soil water in excess of the hygroscopic and capillary capacities, which is free to move under the influence of gravity. It is thus the difference between the "maximum water holding capacity" of a soil and the sum of the other two forms, and is measured by that amount which will flow from a soil having all its pores filled with water. The total drainage from a saturated piece of land would thus represent the gravitational water there present, and the plane in the soil at which all the pores are filled is spoken of as the "water table."

Gravitational water is directly injurious to upland crops, but when it exists at a depth of four to six feet from the surface (water table) it is of untold benefit as a reservoir from which moisture is withdrawn and supplied to growing crops by capillarity. Some deep-rooted plants, as alfalfa and trees, will send down tap roots to the water table when this is far below the point from which water can be raised by capillarity, but this is not the case with most crop plants. We thus see the importance of gravitational water as a reserve for capillary moisture.

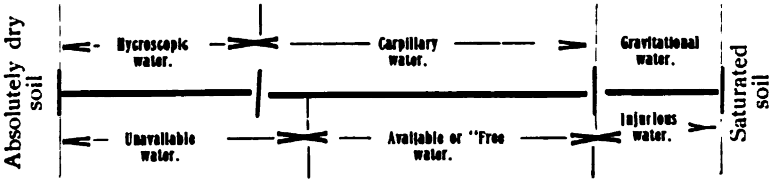
Moisture Available to Crops. We have shown above that the moisture of soils is present in three physical states held by as many forces. I will briefly explain that portion of the soil water which is available to the growing plant. This, by plant physiologists, is termed "free water," and may be defined as that which is free to enter the plant roots and upon which the latter depend for normal growth. As was above stated, none of the hygroscopic water can be used in maintaining growth although Hilgard states that it may sustain or tide over the life of vegetation (especially desert life) during periods of great drought. Not quite all of the capillary moisture is available for normal growth. The following table, compiled from a variety of sources in which a large number of both plants and soils were used, proves this point.

Soil Used.	Percentage of Water	
	When plants wilted	Hygroscopic
Sandy Soil	2.50	1.90
Sandy Loam	6.20	3.98
Silt	9.80	5.20
Silty Loam	12.20	8.40
Clay	14.10	10.50
Peat	49.70	42.30

Under the word "Hygroscopic" are given each soil's "maximum hygroscopic coefficient," the method of determining which will be given in the appendix. It is seen from these figures that plants wilt before all of the capillary water has been absorbed. Schubler, Liebig, Sachs, Hilgard, King, Alway, and others, have contributed to the voluminous literature pertaining to the available or "free water" of soils. Methods have differed, but as a rule that percentage of water in soils at which plants wilt is taken as the lower limit of "free water," while the upper limit is that represented by the optimum moisture capacity or slightly above that. The presence of gravitational water is known to be decidedly injurious to any except swamp vegetation and a few exceptional plants, as rice, indigo, taro, etc.

The following diagram should make very clear the divisions of soil moisture and that fraction which is available to vegetation.

Physical Condition of Soil Water.



Availability of Soil Water to Plants.

From the above discussion it must be evident that a mere statement of the total moisture content of a soil gives practically no information as to the amount of water which is available to plants growing upon that soil. To obtain such information it is necessary to first ascertain the non-available portion of the soil water which experiment has shown to be from 1 to about 6% in excess of the hygroscopic water. This "amount in excess" depends entirely upon the texture of the soil, being 1% or less for sand, 2 to 3% for loams and often as high as 6% for clay soils. Therefore, if we are armed with the hygroscopic coefficient of a soil as well as with its total moisture holding capacity and physical composition, the available or "free water" may be quickly and accurately estimated.

The following studies are confined to the estimation of the maximum moisture holding capacities* and the hygroscopic coefficients** of the several soils under discussion. From these figures the "optimum moisture capacity" and the "free water" have been calculated. All of these data appear in Table II, which follows. The surface soils only were used in these studies.

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* See Appendix, p. 90.
** See Appendix, p. 90.

TABLE II.
Moisture Coefficients of Hawaii Soils.

Plantation	Soil No.	Maximum Moisture Holding Capacity. Percent.	Hygroscopic Coefficient. Percent.	Optimum Moisture Capacity. Percent.	"Free Water" Approximate. Percent.
Hilo-Puna District.					
Waiakea Mill Co......	1	107.7	20.96	65	38
	2	81.1	20.46	48	22
	3	86.3	21.12	52	25
	4	lost	25.07	..	..
Olaa Sugar Co.........	36	lost	24.60	..	..
	37	96.2	26.50	57	24
	38	154.4	26.68	93	54
Hilo and Hamakua Coast District.					
Onomea Sugar Co......	5	77.7	21.14	46	20
	6	87.5	21.52	52	24
	7	84.9	21.68	50	22
	8	78.9	21.52	47	20
Pepeekeo Sugar Co....	23	97.9	22.69	58	28
	24	81.9	20.60	49	22
Kaiwiki Sugar Co......	21	97.9	22.53	58	29
	22	90.5	21.86	54	26
Hamakua Mill Co......	18	83.7	22.00	50	22
	19	116.5	23.97	70	40
	20	100.4	21.06	60	33
Honokaa Sugar Co.....	16	94.5	24.65	56	25
	17	83.7	20.84	50	23
Pacific Sugar Mill.....	14	82.7	19.35	50	24
	15	87.3	22.57	52	23
Kohala District.					
Hawi Mill and Plantation Co.......	25	72.1	17.16	43	22
	26	59.1	15.72	35	15
	27	59.0	18.60	35	13
	28	57.9	16.70	35	14
Kohala Sugar Co......	32	63.6	18.20	38	16
	33	74.2	19.50	45	21
	34	67.8	18.50	40	18
	35	60.3	17.30	36	15
Niulii M. & P. Co......	29	67.5	17.11	40	19
	30	66.4	18.30	40	18
	31	60.4	18.20	36	15
Kau District.					
Hawaiian Agricultural Co......	9	65.4	9.21	40	25
	10	89.7	22.08	54	26
	11	68.0	8.57	40	27
	12	87.7	10.59	52	35
	13	88.8	18.57	53	29

To anyone familiar with soil work, the unusually high moisture capacities of these soils are at once strikingly apparent. The hygroscopic coefficients are at least twice those for soils of similar texture on the mainland. This is due undoubtedly to the excessive amounts of colloidal silica, iron, alumina and humus present. The classification of the four soil areas is justified to a surprising degree by the hygroscopic moisture coefficients. In the Hilo-Puna District, where we encounter soils of very high organic matter content and where, consequently, the soils absorb excessive amounts of water, we find maximum hygroscopic coefficients. The average for this district is 23.7 percent. In the Hilo and Hamakua Coast District where very heavy clay loams are the rule, the average hygroscopic coefficient is 21.8 percent. In the Kohala district where the prevailing type would be classed as a silty clay loam, the average hygroscopic coefficient is 17.7 percent, while in the Kau District where a diversity of soil types exist we obtain a coefficient of 8.57 percent for the fine sandy loams while 22.08 percent is shown for the high humus and fine silt loam types. The total moisture holding capacities as well as the optimum moisture capacities, as would be expected, closely follow the hygroscopic coefficients, being greatest in the Hilo-Puna District, next in the Hilo and Hamakua Coast District, and least in the other two. The average optimum moisture figure for the plantation soils of the entire Island closely approaches 45%. In other words, when a great majority of the soils on the island of Hawaii contain 45% total moisture they are in optimum *physical* condition for the production of maximum crops.

From the figures presented it would seem that the optimum amounts of "free water" for sugar cane would closely approximate 33% in the Hilo-Puna District, followed by 25% in the Hilo and Hamakua Coast area, 28% in the Kau section, and 17% in Kohala.

The higher the moisture capacities of a soil, the plant food supply being adequate, the greater will be the ability of that soil to produce crops. Therefore, looking at these soils from the standpoint of their water relations, one cannot but be favorably impressed.

CHAPTER IV.

CHEMICAL SOIL STUDIES.

(A) PLANT FOOD WORK.

Since the time of Sir Humphry Davy, who in the year 1800 made the first chemical soil analysis, no branch of soil study has received more attention than has been so freely lavished upon the chemical aspects of soil work. In fact, until less than thirty years ago, "soil science" and "soil analysis" were synonymous terms. Bacteria were then but little known, while time spent on physical soil studies was regarded as futile.

Space does not here permit of an historical review of soil chemistry. A brief discussion of this subject appeared in the "Planters' Record" for December, 1916, pages 413 to 422.

Soil chemistry today is but one of several tools in the hands of a soil expert who would give trustworthy information on fertilization, soil management and possible future crops returns. While there is no doubt but that too much stress has, in the past, been laid on soil analysis, there are nevertheless certain questions pertaining to soils which can *only* be answered in a chemical laboratory. Among these may be mentioned the total and the approximately available major plant foods (phosphoric acid, nitrogen, potash and lime), soil reaction, and the presence or absence of alkali salts.

Present day soil chemistry is based on large numbers of comparative results and on averages, rather than endeavoring to correlate fertility with the analyses of individual soil samples. For this reason, in the pages which follow more significance will be attached to averages than to anomalous results obtained on individual soils.

Table III which appears below presents the percentages of total acid soluble phosphoric acid (P_2O_5), potash (K_2O) and lime (CaO) as obtained by the Agricultural Method of analysis,* together with the percentages of total nitrogen,** found in each of the soil samples drawn.

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* See Appendix, p. 91-93.
** See Appendix, p. 93.

TABLE III.

Total Acid Soluble Phosphoric Acid, Potash and Lime and Total Nitrogen in Hawaii Soils.

Plantation	Soil No.	P_2O_5 Percent.	K_2O Percent.	CaO Percent.	Total N Percent.
Hilo-Puna District.					
Waiakea Mill Co.......	1A	0.220	0.082	1.27	1.02
	1B	0.151	0.040	0.42	0.47
	2A	0.260	0.050	1.61	0.84
	3A	0.260	0.040	2.03	0.91
	4A	0.430	0.065	1.61	0.92
Olaa Sugar Co.........	36A	0.303	0.063	3.13	0.93
	36B	0.271	0.082	0.35	0.58
	37A	0.128	0.034	1.09	0.86
	37B	0.175	0.085	0.31	0.46
	38A	0.223	0.058	1.96	0.96
Hilo and Hamakua Coast District.					
Onomea Sugar Co.......	5A	0.310	0.116	0.35	0.54
	5B	0.190	0.095	0.25	0.32
	6A	0.280	0.110	0.31	0.52
	6B	0.190	0.090	0.31	0.44
	7A	0.590	0.120	0.46	0.53
	8A	0.540	0.110	0.38	0.52
	8B	0.240	0.120	0.31	0.32
Pepeekeo Sugar Co......	23A	0.610	0.184	0.49	0.59
	23B	0.480	0.170	0.21	0.33
	24A	0.210	0.208	0.21	0.51
	24B	0.200	0.150	0.14	0.20
Kaiwiki Sugar Co......	21A	0.300	0.208	0.35	0.77
	21B	0.230	0.150	0.21	0.35
	22A	0.820	0.325	0.49	0.56
	22B	0.615	0.220	0.49	0.34
Hamakua Mill Co......	18A	0.990	0.501	0.56	0.46
	18B	0.755	0.390	0.35	0.38
	19A	0.710	0.256	0.49	0.75
	20A	0.581	0.211	0.56	0.71
	20B	0.410	0.170	0.35	0.35
Honokaa Sugar Co......	16A	0.420	0.300	0.45	0.71
	17A	0.460	0.291	0.56	0.40
Pacific Sugar Mill......	14A	0.880	0.330	0.31	0.44
	14B	0.760	0.205	0.38	0.25
	15A	0.720	0.320	0.53	0.58
	15B	0.670	0.280	0.35	0.56

TABLE III—Continued.

Plantation	Soil No.	P_2O_5 Percent.	K_2O Percent.	CaO Percent.	Total N Percent.
Kohala District.					
Hawi Mill & Plantation Co........	25A	0.775	0.412	0.35	0.50
	25B	0.584	0.334	0.14	0.40
	26A	0.437	0.526	0.45	0.48
	26B	0.140	0.453	0.20	0.13
	27A	0.223	0.348	0.34	0.26
	28A	0.271	0.332	0.31	0.30
	28B	0.424	0.431	0.15	0.18
Kohala Sugar Co.......	32A	0.223	0.364	0.38	0.30
	33A	0.191	0.344	0.21	0.46
	34A	0.271	0.576	0.17	0.41
	35A	0.128	0.477	0.29	0.21
Niulii M. & P. Co......	29A	0.303	0.612	0.06	0.41
	29B	0.169	0.809	0.13	0.28
	30A	0.574	0.419	0.17	0.41
	31A	0.399	0.339	0.22	0.30
	31B	0.287	0.230	0.20	0.10
Kau District.					
Hawaiian Agricultural Co.......	9A	0.340	0.410	5.53	0.38
	9B	0.231	0.307	1.82	0.29
	10A	0.340	0.179	3.08	0.28
	11A	0.380	0.210	5.53	0.39
	11B	0.440	0.160	5.74	0.41
	12A	0.200	0.110	3.26	0.47
	12B	0.160	0.142	1.98	0.34
	13A	0.450	0.133	2.98	0.29

Before a discussion of Table III is given, Table IV will be presented. Here are given the percentages of available phosphoric acid (P_2O_5), potash (K_2O) and lime (CaO) as determined by Dyer's one percent citric acid method.* Many different ways have been proposed for the determination of that fraction of a soil's mineral plant food supply which, by natural agencies, will be made available during the growing season of a single crop. Of these, however, none have withstood the years of criticism and repetition on different soil types with the success of the 1% citric acid method proposed in 1894 by Dyer. As with all similar empirical procedures, the minimum limits below which fertilization with either phosphoric acid or potash may be expected to give results, will vary depending upon soil formation and soil type. Dyer's original minimum limits as given for English soils were 0.01% for either phosphoric acid or potash, but from unpublished work in this laboratory, I am inclined to think that, for these laterite island soils, taking into consideration the 18 month's growing season of sugar cane, Dyer's limits as given above are not here applicable. We are at present working along this line in the laboratory by analyzing many soils for citrate soluble phosphoric acid and potash and correlating these figures with yields of sugar obtained, but we are not yet prepared to state definite numerical limits. Indications are, however, that a lowering of the phosphoric acid limit and a slight raising of the potash limit may eventually be shown to more nearly depict our soil condition here. It should be understood that any method for the determination of available plant food is of necessity empirical, and, unless other data are at hand, can never be expected to give more than an indication as to probable limiting factors. The low potash content of certain of the soils as shown in Table IV (Hilo-Puna district) are nevertheless of interest and should be given due consideration in formulating fertilizer practices for these lands.

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* We have slightly modified the original method. See Appendix, pp. 93-95.

TABLE IV.

Available Phosphoric Acid, Potash and Lime in Hawaii Soils.

Soil No.	P_2O_5 Percent	K_2O Percent	CaO Percent	Soil No.	P_2O_5 Percent	K_2O Percent	CaO Percent
Hilo-Puna District.							
1A	0.0136	0.0239	0.126	36A	0.0127	0.0080	0.274
1B	0.0034	0.0080	0.017	36B	0.0083	0.0010	0.096
2A	0.0146	0.0155	0.399	37A	0.0185	0.0150	0.271
3A	0.0176	0.0130	0.459	37B	0.0064	0.0010	0.063
4A	0.0348	0.0157	0.252	38A	0.0217	0.0090	0.277
Hilo and Hamakua Coast District.							
5A	0.0036	0.0128	0.034	22A	0.0086	0.0202	0.171
5B	0.0028	0.0037	0.011	22B	0.0089	0.0225	0.059
6A	0.0038	0.0147	0.028	18A	0.0130	0.0768	0.202
6B	0.0034	0.0039	0.050	18B	0.0090	0.0698	0.109
7A	0.0092	0.0120	0.204	19A	0.0118	0.0621	0.123
8A	0.0064	0.0171	0.081	20A	0.0140	0.0260	0.224
8B	0.0050	0.0316	0.039	20B	0.0102	0.0116	0.084
23A	0.0090	0.0167	0.204	16A	0.0070	0.0210	0.202
23B	0.0054	0.0219	0.064	17A	0.0050	0.0396	0.204
24A	0.0032	0.0326	0.059	14A	0.0018	0.0283	0.056
24B	0.0024	0.0124	0.017	14B	0.0012	0.0082	0.087
21A	0.0104	0.0186	0.087	15A	0.0126	0.0376	0.176
21B	0.0054	0.0159	0.017	15B	0.0090	0.0194	0.092
Kohala District.							
25A	0.0153	0.0561	0.160	33A	0.0166	0.0080	0.106
25B	0.0051	0.0520	0.140	34A	0.0153	0.0230	0.095
26A	0.0147	0.0650	0.280	35A	0.0100	0.0170	0.126
26B	0.0191	0.0150	0.148	29A	0.0083	0.0110	0.118
27A	0.0102	0.0580	0.199	29B	0.0070	0.0020	0.092
28A	0.0166	0.0490	0.123	30A	0.0072	0.0200	0.112
28B	0.0064	0.0370	0.129	31A	0.0179	0.0170	0.134
32A	0.0172	0.0290	0.162	31B	0.0057	0.0110	0.095
Kau District.							
9A	0.0158	0.0578	0.750	11B	0.0096	0.0950	0.526
9B	0.0050	0.0675	0.291	12A	0.0076	0.0605	0.616
10A	0.0080	0.0060	0.493	12B	0.0034	0.0316	0.381
11A	0.0160	0.0757	0.633	13A	0.0236	0.0326	0.526

In the following Table V appear average figures, as computed from Tables III and IV, for the mauka and the makai soils of each district, showing the average percentages of both the total and the available plant food elements together with the amounts of the same in pounds per acre-foot of soil. The average figures for the cane growing lands of the entire Island also appear in the last two columns. Due to the comparatively small number of samples taken when we consider total acreage, these figures are probably not absolute. They are, however, not greatly in error.

TABLE V.

Average Amounts of Plant Food Elements in Surface Soils of Principal Soil Districts.

Plant Food Element	Hilo-Puna District		Hilo and Hamakua Coast District		Kohala District		Kau District		Averages for Hawaii	
	Mauka	Makai	Mauka	Makai	Mauka	Makai	Mauka	Makai	Mauka	Makai
Total P_2O_5,* percentage...........	0.202	0.304	0.425	0.680	0.247	0.340	0.200	0.377	0.268	0.425
Total P_2O_5, lbs. per acre-foot......	6,060	9,120	12,750	20,400	7,410	10,200	6,000	11,310	8,040	12,750
Available P_2O_5, percentage........	0.0156	0.0247	0.0062	0.0095	0.0134	0.0129	0.0076	0.0158	0.0107	0.0157
Available P_2O_5, lbs. per acre-foot...	468	741	186	285	402	387	228	474	321	471
Total K_2O,* percentage...........	0.055	0.055	0.212	0.263	0.456	0.407	0.110	0.233	0.208	0.239
Total K_2O, lbs. per acre-foot.......	1,650	1,650	6,360	7,890	13,680	12,210	3,300	6,990	6,240	7,170
Available K_2O, percentage.........	0.0181	0.0126	0.0220	0.0352	0.0250	0.0376	0.0605	0.0554	0.0314	0.0352
Available K_2O, lbs. per acre-foot....	543	378	660	1,056	750	1,128	1,815	1,662	942	1,056
Total CaO,* percentage...........	1.32	1.87	0.36	0.50	0.21	0.30	3.26	4.28	1.29	1.74
Total CaO, lbs. per acre-foot.......	39,600	56,100	10,800	15,000	6,300	9,000	97,800	128,400	38,700	52,200
Available CaO, percentage.........	0.245	0.329	0.098	0.171	0.128	0.162	0.616	0.600	0.272	0.315
Available CaO, lbs. per acre-foot...	7,350	9,870	2,940	5,130	3,840	4,860	18,480	18,000	8,160	9,450
Total Nitrogen, percentage.........	0.91	0.93	0.60	0.55	0.46	0.33	0.47	0.33	0.61	0.54
Total Nitrogen, lbs. per acre-foot...	27,300	27,900	18,000	16,500	13,800	9,900	14,100	9,900	18,300	16,200
Available Nitrogen, percentage.....	0.00078	0.0022	0.0014	0.0016	0.0031	0.0023	0.0008	0.0030	0.0015	0.0023
Available Nitrogen, lbs. per acre-5"	39	110	70	80	155	115	40	150	75	115

* Total amounts soluble in strong acid.

In discussing of these tables, the soils of each district will be briefly reviewed, but there are a few points of interest common to all. The surface soils, almost without exception, are higher in each of the plant food elements than are the corresponding subsoils, notwithstanding the fact that the cane probably obtains a major portion of its nourishment from the former. The reasons for greater fertility of surface soil are: The plant roots forage in the subsoils as well as nearer the surface, translocating the available food materials chiefly to the aerial portion of the plant. After death or harvesting much of this is left upon the surface. The top foot of soil holds the bulk of the roots with their contained plant food materials. Wind and water cause a constant erosion and deposition of fine mineral and plant debris at the surface. Greater aeration tends to enhanced bacterial activity, and finally, all of the fertilizing materials are incorporated with the surface soils, much of which is fixed in this layer.

The total nitrogen figures are unusually high for cropped lands altho, as shown in the lower two columns of Table V, its availability is low. The availability of soil nitrogen is measured by the rate at which a soil, by means of its own bacteria, can produce nitrates from its insoluble, organic nitrogen.* It will be noticed that here, instead of calculating the available nitrogen in pounds per acre-foot, as has been done with the mineral plant foods, we use the figures obtained for an acre to a depth of 5 inches. This is done because experiments have shown that, due chiefly to lack of air, very little nitrification takes place below this depth. Practically all nitrates found in soils, irrespective of depth, have been formed in the surface 5 or 6 inches (unless applied as nitrates) and have later been carried below by water.

The approximate number of pounds of the several major plant food elements withdrawn from the soil of an acre of land in producing 5 tons of sugar (about 40 to 45 tons of cane per acre) are herewith shown for three common varieties of cane.†

Variety	Nitrogen	Phosphoric Acid	Potash	Lime
Lahaina	127.5	80.0	447.5	145.0
Yellow Caledonia	193.5	85.0	655.0	182.5
D 117	214.5	85.0	619.0	220.0
Average	178.5	83.3	573.8	182.5

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* See "The Determination of Availabiltiy of Nitrogenous Fertilizers in Various California Soil Types by Their Nitrifiability," by C. B. Lipman and P. S. Burgess, Cal. Agr. Exp. Sta. Bul. 260.

"A Vegetation Experiment on the Availability of Nitrogenous Fertilizers in an Arid Soil," by C. B. Lipman and W. F. Gericke, Soil Science, Vol. II, No. 6, pp. 575-581.

† Recalculated and checked from H. S. P. A. Bul. No. 6, Division of Agriculture and Chemistry.

These are the amounts of plant food removed by the complete crop (both cane and trash).

I have arbitrarily chosen this yield of 5 tons of sugar per acre because it is actually obtained upon many of the Hawaii plantations altho it is above the general average. The lowest column of figures shown in Table V, while not giving absolute figures, shows the approximate amounts of available nitrogen, which should be formed from the soil's organic matter per acre, during the two year growing period of a cane crop. When it is taken into consideration that a fair percentage of these amounts are lost thru leaching in those districts of heavy rainfall, it at once becomes apparent, where 178.5 lbs. of nitrogen are required for a 5 ton crop of sugar, that available nitrogen is here present in too small amounts, and must be supplied.

The total lime percentages, as recorded in the above tables, are high (the average is 0.13% for the humid sections of the United States), but in these acid soils (excepting the Kau District) the calcium is entirely present either as complex acid silicates or in the decomposing organic matter.

In either case its availability is low, and, altho present, it is not in proper form for maximum crop yields. The soil acidity work which forms the second part of this chapter throws more light upon the lime situation, as does the bacteriological work in Chapter V.

Potash, both total and available, is apparently present in adequate amounts in practically all of the Hawaii soils examined except possibly in certain fields of the Hilo-Puna District. Dyer has calculated that, using his 1% citric acid method, 300 lbs. of available potash per acre-9 inches is the lower limit below which fertilization with potash should result in profit. Referring again to the average composition of cane, we find that about 574 pounds of potash are required to produce a 5 ton sugar crop. Of this, approximately ⅔ are contained in the trash while ⅓ is contained in the cane. The latter is removed from the field, while, if the cane is burned before cutting, a part of the former is lost on the wind and thru volitilization. Taking an average figure of say 350 lbs. of potash per acre per crop, any plantation interested may, by referring to Table VI obtain a comparative idea as to the condition of his soils regarding the supply of this element in available forms. While but a few fields in this district go below Dyer's limit several sections are so near it as to probably justify present potash applications, especially when we consider that Dyer's limit, which was given for small grains, is considerably *below* that required for a 5 ton sugar crop. The supply and cost of potash will, of course, at this time militate against its extensive use.

It is an established fact that practically all of the potash in the cane juice goes through into the final molasses. In order to have been taken up by the plant, it must previously have existed in an available form in the soil. After having determined the total and available potash in the soils of the several plantations it was thought worth while, as a check on this work and as a means of obtaining further information on the soils in question, to determine the total amounts of potash as well as ash, in the final molasses of the several plantations whose soils had received attention. Due to the different amounts of water used in washing, etc., the several samples differed considerably in moisture content, specific gravity, and in sugar and salt content. For this reason it was thought that the percentages of potash in the molasses ashes would here be the better comparative figures. The following Table VI records the amounts of soil potash, both total and available, the amounts of potash† and ash in the molasses, and the percentage of potash in the ash, from each plantation investigated.

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† For method of determination, see Appendix, p. 96.

TABLE VI.

Potash in Soils Compared with Total Potash in Molasses and in Molasses Ash.

Plantation	Olaa S. Co.	Waiakea Mill Co.	Onomea S. Co.	Pepeekeo S. Co.	Kaiwiki S. Co.	Hamakua Mill Co.	Honokaa and P. S. M.	Hawi M. & P. Co.	Kohala S. Co.	Niulii M. & P. Co.	Hawaiian Agr. Co.
Total potash* in soils:											
Average percentage	0.064	0.057	0.110	0.180	0.226	0.305	0.288	0.405	0.440	0.482	0.208
Total potash in soils:											
Average lbs. per acre-foot	1,920	1,710	3,300	5,400	7,780	9,150	8,640	12,150	13,200	14,460	6,240
Available potash in soils:											
Average percentage	0.0070	0.0152	0.0137	0.0209	0.0193	0.0492	0.0257	0.0477	0.0200	0.0122	0.0533
Available potash in soils:											
Average lbs. per acre-foot	210	456	411	627	579	1,476	771	1,431	600	366	1,599
Total potash in molasses:											
Percentage	1.490	1.660	2.548	2.590	3.100	2.470	3.039	5.493	3.500	3.679	3.877
Total ash in molasses:											
Percentage	9.00	8.64	10.52	10.43	10.67	9.30	11.00	13.14	10.59	12.00	10.10
Percent potash in the ash...	16.5	19.2	24.2	24.8	29.0	26.5	27.6	41.8	33.0	30.6	38.3

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* By "Total potash" is meant the total amount of potash extracted with strong acid, using the Agricultural method of analysis.

An inspection of this table will show that the amounts of potash found in the molasses compare exceedingly well with the percentages found in the soils of the several plantations. A low figure for potash in the final molasses and in the molasses ash invariably accompanies a low total or available potash percentage for the soils of that plantation, and vice versa. The evenness of the "percent potash in ash" figures for the plantations of the individual districts is very noticeable indeed. Table VII compares the average amounts of potash in the soils of the several districts with the corresponding average potash figures in the molasses.

TABLE VII.

Average Soil and Molasses Potash of the Different Soil Districts Compared.

	Hilo-Puna District.	Hilo and Hamakua Coast District.	Kohala District	Kau District.
Total acid soluble potash in soils:				
Average percentage	0.060	0.220	0.442	0.208
Available potash in soils:				
Average percentage	0.0111	0.0257	0.0266	0.0533
Total potash in molasses:				
Average percentage	1.575	2.749	4.224	3.877
Total ash in molasses:				
Average percentage	8.82	10.38	11.91	10.10
Average percentage of potash in ash..	17.8	26.4	35.1	38.3

With but one exception all of the figures uniformally increase from left to right, i. e., the soils of low potash content invariably produce molasses of low potash content. The only exception is the arid Kau District, where, altho the total acid soluble potash is low, the available potash is almost twice that reported from any other district. This high potash availability is due entirely to the climatical conditions under which these Kau soils have existed. There has been a minimum of leaching; the soils are almost all alkaline in reaction, and they are high in organic matter; all of which promotes maximum bacterial activity accompanied by high mineral availability. An excess of lime as carbonate and bicarbonate as a rule indicates high potash availability thru chemical interchange of bases. This is a minor reason for the application of lime in the other districts on Hawaii.

Phosphoric acid, while high in total amount (the average for humid mainland sections is 0.12%) is present in these Hawaii soils chiefly as iron and aluminum phosphates which are but very slowly made available (see columns 2 and 6 of Table IV). This is especially true of the soils along the Hilo and Hamakua Coasts (see Table V). It is noteworthy however, that much less phosphoric acid is required to produce a 45 ton crop of cane (only about 83 lbs. per acre) than is the case with any of the other major mineral plant food elements. For each pound of phosphoric acid used by the growing cane, about 2¼ pounds of lime, 2¼ pounds of nitrogen and 7 pounds of potash are reqiured.

Let us now briefly discuss the plant food situation in the several soil districts as set forth in Tables III, IV, V, VI and VII. No attempt will be made to discuss the soils of each individual plantation but the complete data for each are presented in the tables.

The Hilo-Puna District.

In this district are located three plantations and a small portion of a fourth. The surface soils are composed mainly of organic matter. This is the district of heaviest rainfall and, in the past, excessive tropical growth abounded. The mauka soils are usually underlain by a stiff, putty-like, clayey subsoil ranging in color from a light drab or gray to a light brown. This material is often richer in potash and in phosphoric acid than are the surface soils, but poorer in nitrogen and lime.

A former report† on the mauka subsoils of the Olaa Sugar Company and the Waiakea Mill Company shows them to be composed chiefly of oxides of aluminum and iron. An average of over 54% of the mineral matter is soluble in hot 4% hydrochloric acid. Silica is present in very small quantities; about 46% of it in soluble forms. As these soils, in the field, due to excessive rainfall, always contain about 75% water, it may be safely stated that they consist almost entirely of aluminum and iron hydrates, hydrated silicates of these elements, calcium and magnesium, and organic matter. It may be of interest to state that, when completely saturated, these soils hold about five times their own dry weight of water. Having been formed from the decomposition of lava rock (which is present at a depth of about

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† Unpublished data, by Firman Thompson.

2½ feet from the surface) under the evenly distributed and high rainfall of this district, these compounds have retained their water-holding properties to a surprising degree. The fact that these subsoils after having been thoroughly air-dried do *not* again return to the same physical condition when rewetted, proves that dehydration has never taken place to any great extent in the past. Experiments have shown the practical impossibility of drainage. It is thus to be expected that, altho nitrogen is present in the shallow surface soils to the extent of about 1%, bacterial activity is low. High altitude and low temperatures also tend to contribute to this condition (see Chapter V). Conditions should here be favorable for the formation of soil toxins, especially reduced iron compounds. Several carefully planned experiments have, however, failed to show any such compounds in condition to be taken up by plants. This does not, of course, preclude the presence of organic soil toxins.

The makai surface soils are similar to the above but usually deeper and darker in color. They are often underlain at a depth of 9 or 10 inches by solid lava rock, usually aa, altho pahoehoe formations are not uncommon. This latter tends to greatly restrict rooting area over certain sections. The surface soils of this district are quite acid requiring from 1 to over 13 tons per acre of lime carbonate, depending on location (see 2nd part of this chapter), altho both total and available lime figures are high.*

Lime is thus here needed as a corrector of soil acidity only.

The first two columns of Table V present the average plant food data for both the mauka and the makai soils of this district. The lower soils are, as a rule, better supplied than are the higher lands.

The "total potash" figure for this area is low when comparted with the other districts as is also available potash. The total potash percentages in the molasses and in the molasses ashes from the mills of this district are also the lowest of any on the Hawaiian Islands (see Table VII, and H. S. P. A. Bulletin No. 16, "Hawaiian Waste Molasses," by S. S. Peck, pages 22 and 23). The total phosphoric acid figures are also decidedly below the average for the Island altho available phosphoric acid is fair. Total nitrogen, as would be expected is very high. The available nitrogen mauka is low but makai it is the highest of any area.

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* As stated above, this lime is present in organic form chiefly, although some is doubtless present as complex, acid silicate.

The Hilo and Hamakua Coast District.

This is the largest continuous cane growing section on the Island. It comprises a strip of land along the north eastern coast of Hawaii 50 miles long by from 3 to 4½ miles wide. Twelve plantations are located in this district. The soils are all quite similar, the differences noted being in large part due to the methods of soil management which have prevailed in the past. Thus, certain plantations have turned in trash, applied lime and green manured while others have used concentrated commercial fertilizers only. The results are today apparent; in fact certain of the soils have been entirely changed for the better, while of others the reverse is true. The soils up and down this coast would, with the exception of a few small areas, be classed as heavy clay loams of fairly high organic matter content. The surface soils vary in depth from about 5 inches, mauka, to from 12 inches to two feet, makai. The subsoils are, as a rule, quite similar to the surface soils, but lighter in color.

The percentage of total phosphoric acid both in the mauka and makai soils far surpasses that of any other district, but, due to high iron content, the available phosphoric acid is here at a minimum (see Table V).

Both total and available potash are fair when compared with averages from the other districts, being much higher than the Hilo-Puna District, a little lower than the Kau District, and much below Kohala.

Lime, both total and available, is low. The soils of this district are the most acid of any on the Island (see second part of this chapter).

In total nitrogen this district is next to the Hilo-Puna District, surpassing both Kohala and Kau. The *available* nitrogen is low, due chiefly to high soil acidity, with attending low bacterial efficiency. The mauka soils of all districts, without exception, run higher in total nitrogen and lower in available nitrogen than do the lower fields. This is probably due to the excessive rainfall as well as to the lower temperatures prevailing at the higher elevations. The higher fields are also considerably more acid than the makai areas.

The Kohala District.

Five plantations comprise this district which is located on the northern coast of Hawaii (Kohala Coast). The soils here are fairly uniform when the extent of the area is considered, being for the most part, silty clay loams of high humus content. They are as a rule deep, in good tilth, and of high potential fertility. These lands are far less acid than are the soils of the two districts previously discussed, and carry high quantities of available plant foods. The rainfall is here considerably lower and in certain sections irrigation is intermittently practiced.

Phosphoric acid, lime and nitrogen are present in fair amounts, while potash both total and available, is unusually high.* While a majority of the soils are slightly acid, no such amounts of lime are required as in the Hilo-Puna and Hilo and Hamakua Coast Districts. The mauka fields are much lower here than elsewhere on Hawaii; with but few exceptions the cane land is below 1500 feet elevation. This not only indicates warmer weather with lengthened growing season, but also deeper soils for increased root development. Considered chemically, these soils are potentially the most fertile on Hawaii.

The Kau District.

But two plantations are located in this district which is on the southern coast. We find here a considerable variation in soil type altho sandy and silt loams predominate. Mauka are found the same high humus soils, while volcanic mud flows have produced a stony loam type. This district is located in the semiarid belt, and, where water is obtainable, irrigation is practiced.

The soils, while slightly lower in total acid soluble phosphoric acid and potash, are well stocked in *available* phosphoric acid and are the highest on the Island in *available* potash. The total percentages of the latter in the molasses, as well as its percentage in the molasses ashes, are higher than similar figures for any other district. (See Table VII.) In lime, also, these soils lead, practically all of them showing an alkaline reaction. A glance at Table V shows the soils in question to contain a very good percentage of total nitrogen which, compared with the other districts, is quite readily available.

Water is here probably an important factor limiting cane production.

(b) SOIL ACIDITY WORK.

The practice of liming the land is almost as old as agriculture itself. The Chinese were probably the first to use it, followed by the Romans, who later introduced it into France and England.

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* The total percentage of potash in the molasses from the mills of this area are among the highest for the entire island.

In England the practice of "marling" has been followed for centuries with marked results. The first mention of lime in connection with American agriculture is to be found in the writings of Ruffin in the "American Farmer" of 1818, since which time the practice has extended to every agricultural section in our country.

Lime should never be considered a fertilizer in the same sense as are barnyard manure and dried blood. It can never take the place of these but should be used in connection with them. The element calcium is the only essential element supplied by lime, and most arable soils contain a sufficient amount of this element to meet maximum plant food requirements. The benefits from lime come in correcting untoward soil conditions which are inimical to maximum crop yields. Stated differently, when unproductiveness is due to lack of lime it is, in nine cases out of ten, caused by *acidity* and not by lack of lime as plant food.

We find in recent literature the terms "active," or "true acidity" and "passive," or "apparent acidity." By the former term is meant the absolute presence in soils of organic acids formed from and during the decay of large amounts of organic materials. By the latter term is signified the absorptive power of soils containing considerable quantities of colloidal materials for soluble lime compounds. In either case basic lime is removed from the soil solution and rendered inactive.

Soil acidity may be due to any or several of the following causes. The original minerals from which the soil was derived may have been low in basic compounds (this is not true of our Island soils); large crops of lime-loving plants may have depleated the soil of calcium; drainage water each year removes from 300 to 600 pounds of lime carbonate per acre (more in districts of excessive rainfall); soils containing large quantities of fermenting organic matter may utilize all bases present in neutralizing the organic acids formed; the use of certain commercial fertilizers as sulfate of ammonia and acid phosphate results in the gradual accumulation of mineral acids; poor drainage, while not directly causing acidity, undoubtedly contributes to this condition by effecting a reduction of certain sulfur and organic compounds. It is a characteristic of soils, to absorb basic compounds, which in all probability accounts for a great majority of acid, mineral soils, altho certain peats, mucks and other lands, as our mauka fields, which carry large amounts of decomposing organic matter, do doubtless form and contain small amounts of active organic acids.

Be that as it may, we do know that soils rendered acid by whatsoever cause are more or less unproductive, but can be "sweetened" by the use of lime.

What is Lime? Pure lime is a chemical compound composed of the elements calcium and oxygen (CaO), the two being united in the proportion of 40 parts by weight of calcium to 16 parts of oxygen. This compound ("quick lime"), when exposed to moist air or artificially wetted, absorbs water with evolution of heat to form the fine white powder which we call slacked or hydrated lime, $Ca(OH)_2$. In the process of slacking, lime absorbs about 32% of its weight of water. When this slacked lime is exposed for some time to the air it absorbs carbonic acid (CO_2) and gradually changes to carbonate of lime ($CaCO_3$), which is the form in which it exists in natural limestones and in coral sand. If we now heat this limestone, the carbonic acid gas is driven off together with any water that may be present and we have caustic lime or "quick lime" (CaO) again. Pure carbonate of lime ($CaCO_3$) consists of 56 percent of lime (CaO) and 44 percent of carbonic acid (CO_2). Thus, 100 pounds of lime carbonate contains 56 pounds of lime (CaO); 100 pounds of hydrated lime contains 74 pounds of lime, while "quick lime" and "lime" are synonomous terms. In most natural limestones the lime is associated with magnesia, iron, aluminum, silica, and other impurities. Coral sand averages about 87% lime carbonate, while calcite, the purest form of natural limestone known, may run above 99%.

The Form of Lime to Apply. As shown above, there are three forms of lime which may be applied to soils to correct soil acidity; the oxide or "quick lime"; the hydrate, or slacked lime; and the carbonate. That form should be used which can be obtained at the least price per unit of calcium oxide (CaO) at the same time taking into consideration the effects of the different lime compounds upon the soil. Much time and money have been spent experimenting upon this point by several of the large mainland experiment stations, notably at Pennsylvania, Illinois, Ohio, Rhode Island, New Jersey, New York and Maryland. Space does not here permit detail, but the concensus of opinion certainly is in favor of the carbonate form. To quote from Bulletin No. 131 of the Pennsylvania Experiment Station where liming experiments have been carefully conducted for over 30 years on the same land growing many different crops, "All of the field tests are more favorable to the finely crushed limestone than to equivalent amounts of burned lime." Similar statements may be found in bulletins from practically all the stations where tests of this kind have been made. To quote from New York Agricultural Experiment Station Bulletin No. 400, "Nine years of comparative trials at the Ohio Station, four at the Tennessee Station, eleven at the Maryland Station and much other evidence both from this country and abroad prove that limestone (calcium carbonate) gives at least as good and usually better results than its lime equivalent in other forms. Quicklime occasionally appears to injure land and crops through its caustic properties, but ground limestone, being chemically neutral, can never harm either soil or crop." This bulletin then gives data favoring ground limestone applications.

In a recent article, "The Effect of Quicklime on Organic Matter in Soils,"* Mr. F. E. Bear of the West Virginia Experiment Station summarizes as follows, "The results show that in every case the plots receiving quicklime, as compared with the plots receiving a corresponding fertilizer application without quicklime, show a lower content of both nitrogen and carbon. The results thus indicate that quicklime does reduce the amount of carbon and nitrogen in the soil."

The Experiment Station of the H. S. P. A. strongly recommends the use of lime as carbonate. We do not advocate burned lime for the following reasons; it is more expensive; it is harder to handle and, if accidentally moistened, it tends to cake badly, rendering uniform spreading difficult, if not impossible, and it burns out the soil's organic matter where it is necessary to apply it in large quantities.

Of the several different varieties of lime carbonate, i. e. coral sand, ground coral rock, ground limestone, etc., we recommend finely ground coral rock in preference to coral sand providing the former can be profitably obtained.

Testing for Acidity. Altho a piece of litmus paper pressed against a portion of moist soil will often give one a fair idea as to acidity or alkalinity, it does not give even an approximation as to the correct amounts of lime to apply per acre in case lime is required. Furthermore, certain soils on these Islands are of such a pronounced red color as to render inconclusive the litmus test. For these reasons we advise those desiring advice along this line to send us samples of soil which we will be pleased to analyze and report upon. At least a dozen methods have been proposed for this determination. After having tried out several in this laboratory we have returned again to the Standard Veitch Method as modified by White.† Altho longer and more tedious of manipulation, we still feel that the results obtained by it are more in accord with field practice, both here and on the mainland.

Why Liming is Justified. Lime may well be considered the universal corrector of soil faults. Physically, it improves tilth by cementing together and rendering less pervious light sandy soils, and by flocculating the clay and rendering tractible stiff, heavy clay lands. Chemically, it supplies one of the essential elements of plant food, calcium; it renders potash and phosphoric acid more available to the growing plant, and, most important of all, it corrects soil acidity, thus rendering a soil "sweet" and capable of producing its maximum crop. Bacteriologically lime is of prime importance. Very little ammonification and nitrification can take place in an acid soil, and practically no nitrogen fixation. Most legumes prefer a non-acid soil, many of them absolutely failing under acid conditions. The free living azotobacter forms of nitrogen-fixing bacteria which do not live in symbiosis with legumes, but on the decomposing plant remains in the soil, can take up no nitrogen from the air if the soil in which they exist is acid in reaction. These facts have all been repeatedly verified and we know them to be correct.

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* Journal American Society of Agronomy, 8 (1916), No. 2, pp. 111-113.
† See Appendix, p. 96.

Experimental.

The correct amounts of lime to exactly neutralize the soil acidity present in the representative fields from the several districts have been determined and appear in Table VIII. It will be recalled that the surface soils vary in depth from 4 to about 18 inches. In computing the table, allowance has been made in each case for the proper surface soil depth. For convenience, depending upon the form in which it is desired to apply the lime, figures for the oxide, the hydrate and the carbonate are given. Under each form of lime the first column shows the number of tons required per acre to correct acidity in the *surface soil;* the second column, the amount to apply to neutralize the upper two feet of the subsoil, and the third, the sum of these two, or the amounts of lime required by approximately the surface three feet of soil (where a great majority of the sugar cane roots are found).

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Carbonate of Lime		
Surface Soil	**Sub-soil**	**Total**
3.56	16.02	19.58
2.94	....	2.94
1.00	....	1.00
6.67	....	6.67
6.00	21.35	27.35
4.00	29.37	33.37
13.00	....	13.00
4.66	23.50	28.16
4.66	20.00	24.66
10.00	....	10.00
4.40	7.47	11.87
	Alkaline	
7.21	14.41	21.62
11.25	26.70	37.95
8.19	24.00	32.19
3.74	10.68	14.42
6.67	....	6.67
8.33	56.00	64.33
8.00	....	8.00
1.60	....	1.60
8.00	29.90	37.90
8.54	29.90	38.44
4.00	5.34	9.34
1.78	Alkaline	1.78
	Alkaline	
2.14	4.28	6.42
1.78	....	1.78
3.74	....	3.74
6.67	....	6.67
4.00	....	4.00
5.60	18.69	24.29
7.47	....	7.47
2.67	Alkaline	2.67
1.34	Alkaline	1.34
	Alkaline	
	Alkaline	
0.89	16.00	16.89
	Alkaline	

The data here presented require little comment. The most acid soils appear along the Hilo and Hamakua Coast where the average lime requirement for the surface soils is 6.3 tons per acre of lime carbonate. The Hilo-Puna District comes next with a lime requirement of 5.3 tons of lime carbonate per acre, followed by the Kohala District requiring 3.6 tons. The surface soils of the Kau District are, as a rule, alkaline, denoting a sufficiency of lime.

The figures given in the above table represent the absolute amounts of lime necessary to *completely neutralize* the several soils. Whether it would pay financially to add the amounts indicated for both surface and subsoils or whether it would be better to apply half or two-thirds of these quantities is a question which can only be answered by experiment for it appears that cane is very resistant to soil acidity as has been shown by past crops on acid lands. There is no doubt however but that the neutralization of the surface soils would pay, for practically all beneficial bacterial action occurs in this layer. The benefits of liming are strikingly shown in the bacteriological studies which follow.

As has been stated above, we strongly advise the use of *carbonate* of lime. It happens that there are two different varieties of lime carbonate obtainable upon these Islands; finely ground coral limestone, and coral sand. From experiments conducted at this station on the abilities of these two forms of carbonate to correct soil acidity, we have shown that one and one-half tons of the coral sand are approximately equivalent to one ton of the finely ground coral limestone.* Thus, where coral sand is to be applied, the figures in the "Carbonate of Lime" columns of Table VIII should be multiplied by one and one-half to give correct amounts of this material to apply.

(c) ALKALI WORK.

While it was deemed highly improbable that alkali salts (sodium chloride, sodium sulfate and sodium carbonate) could exist for any length of time in soils receiving Hawaii's rainfall, nevertheless it was decided to analyze the soils for these ingredients as a precautionary measure, for Lahaina cane, it will be remembered, first gave out on Hawaii, and we are inclined to attribute its deterioration on the other Islands, in part at least, to the presence of these toxins.

Accordingly all of the surface soils were analyzed by the "New Method"† for alkali with the results set forth in Table IX.

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* "Finely-Ground Coral Rock vs. Coral Sand as a Corrector of Soil Acidity," by P. S. Burgess, Planters' Record for March, 1917, pp. 212-219.

† See Planters' Record, Vol. XIV, No. 5, p. 322; also Appendix, p. 98.

TABLE IX.

Percentages of Alkali Salts in Hawaii Soils.

Soil Number	White Alkali, % NaCl	Black Alkali, % Na_2CO_3	Soil Number	White Alkali, % NaCl	Black Alkali, % Na_2CO_3
1 A	0.015	0	20 A	0.015	0
2 A	.015	0	21 A	.050	0
3 A	0	0	22 A	.015	0
4 A	.010	0	23 A	.010	0
5 A	.015	0	24 A	.015	0
6 A	.020	0	25 A	0	0
7 A	.010	0	26 A	0	0
8 A	.015	0	27 A	.010	0
9 A	.015	.004	28 A	0	0
10 A	.010	.009	29 A	0	0
11 A	.005	trace	30 A	.015	0
12 A	.015	trace	31 A	0	0
13 A	0	trace	32 A	.015	0
14 A	.010	0	33 A	0	0
15 A	.008	0	34 A	0	0
16 A	.005	0	35 A	.010	0
17 A	.010	0	36 A	0	0
18 A	.030	0	37 A	.010	0
19 A	.020	0	38 A	.020	0

Qualitative tests were made in each case for water soluble sulfates with uniformally negative results.

A discussion of the results portrayed in Table IX would be superfluous, for the amounts of alkali in all cases are far too low to cause trouble.

CHAPTER V.

BACTERIOLOGICAL SOIL STUDIES.

A detailed account of the importance of bacteria to soil fertility appeared in Chapter I.

For convenience in tabulation and discussion, the bacteriological studies on these soils have been divided into three parts; first, the ammonification in soils of nitrogenous organic matter, which is the first step in accomplishing nitrogen availability; second, nitrification, or the oxidation of ammonia thus formed to nitrates; and third, nitrogen fixation, or the power of a soil, through certain forms of bacteria living therein to transform atmospheric nitrogen into the protein of their own body cells which subsequently, by the first two processes named, is converted into suitable forms for plant use.

Ammonification. When organic matter of any kind is added to a soil it decays. At first insects and the lower forms of plant and animal life, as molds, fungi and earthworms, act. These are closely followed by the cellulose-destroying bacteria, which by means of the enzyme *cytase,* dissolve the cellulose which composes over 90% of the cell walls of this dead material. The great army of ammonifying bacteria here step in and, by means of the proteolitic enzymes which they secrete, transform the insoluble plant and animal protein-nitrogen into ammonia. This, in the soil solution, at once forms ammonium carbonate. Thus the first great step in the transformation of soil nitrogen is accomplished. A neutral or slightly alkaline soil is not as essential to this process as is the case with either nitrification or nitrogen fixation. Experiments have shown that available phosphoric acid and large quantities of decomposing organic matter are here of most benefit.

All of the surface soils sampled were examined, by the standard method* now in vogue, for their ammonifying powers. These results appear in Table X which follows. The figures are averages of closely agreeing duplicate determinations in each case.

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* See Appendix, p. 97.

TABLE X.

Ammonification Results.

Soil No.	Ammonia Nitrogen per Culture, Mgms.	% of added Nitrogen Ammonified
Hilo-Puna District.		
1 A	18.50	13.70
2 A	25.50	18.89
3 A	25.91	19.20
4 A	32.50	24.07
36 A	16.66	12.34
37 A	16.38	12.13
38 A	17.22	12.75
Average	21.81	16.15
Hilo and Hamakua Coast District.		
5 A	18.40	13.63
6 A	15.00	11.11
7 A	11.30	8.37
8 A	21.60	16.00
23 A	23.10	17.11
24 A	25.90	19.18
21 A	14.00	10.37
22 A	23.50	17.40
18 A	27.30	20.22
19 A	18.90	14.00
20 A	10.20	7.55
16 A	14.00	10.37
17 A	22.20	16.44
14 A	20.60	15.26
15 A	28.10	20.81
Average	19.60	14.52

Soil No.	Ammonia Nitrogen per Culture, Mgms.	% of added Nitrogen Ammonified
Kohala District.		
25 A	22.40	16.60
26 A	28.98	21.47
27 A	17.64	13.06
28 A	42.84	31.74
32 A	25.34	18.77
33 A	22.40	16.60
34 A	28.28	20.95
35 A	19.18	14.20
29 A	16.31	12.08
30 A	24.22	17.94
31 A	30.24	22.40
Average	25.25	18.71
Kau District.		
9 A	7.20	5.33
10 A	27.30	20.22
11 A	10.30	7.63
12 A	12.60	9.33
13 A	28.00	20.74
Average	17.08	12.65

These ammonification figures are considerably below those for a majority of mainland soils altho the amounts of nitrogen transformed are sufficient for good cane yields *providing* nitrification subsequently keeps pace with this process. Later results will show this hardly to be the case. The soils of the Kohala District lead in their abilities to produce ammonia from organic nitrogen, closely followed by those of the Hilo-Puna District, the Hilo and Hamakua Coast District and the Kau District, in the order named. That soil acidity has little effect on ammonification is well illustrated by these average results, the alkaline soils of the Kau area making the poorest showing of all. A portion of the ammonia nitrogen here originally formed has doubtless been transformed during incubation into nitrate by the vigorous nitrifying flora of these alkaline soils, which, of course, would tend to lower apparent ammonification. The higher figures for the more acid districts confirm certain of Kelley's results. He states,[†] "From the experiments recorded it has been shown that calcium carbonate (lime) produced only slight stimulation of ammonification of dried blood and soy bean cake meal in most of the [acid] soils studied."

It is interesting to note that active ammonification follows closely the available plant food content of the several districts. This is not universally true for potash, but here we are probably dealing with an element which is present in sufficient quantities for this process in all of the soils studied. (See Table IV).

In conclusion it may be stated that, altho not high, ammonification is probably not generally limiting nitrogen availability in these soils.

Nitrification. This is the second and final step in the bacterial preparation of nitrate-nitrogen in soils. The ammonia, as formed above by the ammonifying species of bacteria, is here oxidized, first to nitrites, and finally to nitrates. The great practical importance of nitrification is evident when once we consider that virtually all dry land crops of necessity take up the great bulk of their nitrogen in the form nitrates. Though it is known that plants are able to utilize ammonia-nitrogen to a limited extent, physiological disturbances follow where this form alone is obtainable.

The following conditions are essential for the production of soil nitrates: 1st. The presence of the nitrifying bacteria in sufficient numbers; 2nd, proper moisture and temperature conditions; 3rd, good aeration to supply the necessary oxygen for oxidation; 4th, an ***alkaline soil reaction*** to neutralize the nitrous and nitric acids as they are produced.

This latter point is well borne out, not only by our experiments which follow but also by White of the Pennsylvania Station.[*] He shows that, while nitrification does not absolutely cease in very acid soils, it is far below that for neutral or alkaline lands. Referring to the very acid soils of the ammonium sulfate plot, he states, "Applications of burned lime and ground limestone to soil from this plot materially stimulated the activity of nitrifying organisms. Magnesian lime gave higher nitrates than pure lime."

The effect of low temperatures in checking nitrification as well as other beneficial bacterial processes is readily noted in retarded cane growth during the cooler winter months, when, as a rule, nitrate fertilization is advisable to "boost the cane along." This is especially true at the higher elevations. That proper moisture conditions must prevail goes without saying, for no nitrates can be produced in either dry or waterlogged soil.

[†] Bulletin No. 37 of the Hawaii Experiment Station, "Ammonification and Nitrification in Hawaiian Soils."

[*] "Nitrification in Relation to the Reaction of the Soil," Penn. Annual Report, 1914, pp. 70-80.

Nitrification is accomplished by the addition of atmospheric oxygen to the ammonium carbonate molecule as per the following equations:

$(NH_4)_2CO_3+6O=2HNO_2+H_2CO_3+2H_2O$ (nitrous acid).
$2HNO_2+CaCO_3$(base)$=Ca(NO_2)_2+CO_2+H_2O$ (nitrites).
$Ca(NO_2)_2+2O=Ca(NO_3)_2$ (nitrates).

It thus follows that any cultivation process which tends to aerate the soil will result in enhanced nitrate production.

The effect on nitrification of neutralizing these acid Hawaii soils with lime carbonate will be discussed later after inserting Table XI. This table presents all of the nitrification data and will repay detailed study. Six complete series of nitrification experiments were performed.

The first two columns give the laboratory numbers as well as the plantations from whence the soil samples came. The third column shows the amounts of nitrate nitrogen in 100 gram portions of the original soils as taken from the fields and dried.† The horizontal lines of figures labeled "Average" present the averages in the several columns for the *surface soils* of each district, thus giving comparable results directly across the page as *only* the surface soils were used in the last three series. The six series will be discussed separately, after which the average figures for the several districts will receive brief attention.

Series 1. In this series no extra nitrogen was added. The soils were incubated for 28 days at proper moisture and temperature, the object being to ascertain how much of the soil's own organic nitrogen it could convert into nitrate under standard conditions. With this learned, the rate at which the soil nitrogen was made available as well as the total amounts of nitrate nitrogen produced per crop could be fairly accurately estimated. The average figures thus obtained for each district (as calculated from Table XI) have already been presented in the lower two columns of Table V.

The first column of Series 1 shows the total amounts of nitrate nitrogen found per culture (expressed as milligrams of nitrogen), while the second column shows the percentages of the soils' original total nitrogen (see Table III, last column) which have

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† As 100 grams of dry soil is the amount taken for each of the nitrification cultures, these blanks may be directly compared with any culture of the same soil.

been nitrified. As would be expected, in practically all cases the surface soils excell in nitrifying their own nitrogen. The average amount of soil nitrogen converted into nitrate nitrogen for the surface soils of the entire island is 3.06 mgms. per culture or 0.44% of the total nitrogen therein present, while similar figures for the subsoils are 0.90 mgms. or 0.15% converted. These figures are low when compared with mainland soils. Some years ago while at the California Experiment Station the writer conducted a prolonged series of nitrification tests on soils obtained from the experiment station grounds of each state and territory in the United States besides several of the insular stations and Canada, using dried blood, ammonium sulfate and cotton seed meal as the sources of nitrogen.* As these experiments were conducted in the same manner as those reported in this bulletin, they may be directly compared. The figures appearing at the bottom of Table XI are averages of these tests and should fairly well represent the average nitrifying powers of mainland soils. The average amounts of residual nitrate in the field soils of Hawaii and the United States are almost identical (column three), but the amounts of soil nitrogen made available on incubation are over five times as great in American soils as in those of Hawaii (columns 4 and 5). This is doubtless due in part at least to the excessive soil acidity in these Hawaii soils. It cannot be due to lack of soil nitrogen for Hawaii soils carry two or three times as much of this element as the average soils of the United States.

There is a loss of original nitrate (doubtless supplied in fertilizers) in two cases, indicating denitrification, and no nitrate production in four other cases. Of these six cases, but one surface soil is at fault. This is exceptionally good when we consider the large number of soils examined, and bespeaks the fact that the nitrifying bacteria are universally distributed in these soils and simply await proper conditions (neutralization of soil acidity) to spring into activity. Later discussion will prove this point.

Series II. Here ammonium sulfate at the rate of 0.2 gram per culture (42.4 mgms. of nitrogen per 100 grams of soil) was used. This is equivalent to an application of about 2 tons of ammonium sulfate per acre, but, as the standard period of incubation is but 4 weeks, these quantities have been proven necessary. As will be seen upon consulting columns 6 and 7, Table XI, this material is quite readily nitrified even in some of the more acid soils. Whereas but 23.75% of the nitrogen in am-

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* A full account of this work may be found in The Journal of Agricultural Research, Vol. VII, No. 2, pp. 47-82.

Plantation	Soil Number.	Original nitrate-nitrogen in
	1A	
Hawaiian Agr. Co....	9B	
	10A	
	11A	
	11B	
	12A	
	12B	
	13A	
Average............		

Surface Soils........		
Sub-soils............		

Aver

Surface Soils........		
Sub-soils............		

Research, Vol. VII, No. 2, pp. 47-82.

monium sulfate is nitrified in the average mainland surface soil during the 4 weeks incubation period, 48.9% is changed to nitrate as an average on Hawaii. As remarked in a previous article,† the plantation soils of the entire Hawaiian Group are very vigorous in their abilities to nitrify ammonium sulfate. The reason for this is somewhat abscure unless it be that continued application of this material as fertilizer has increased the ability of the nitrifiers to transform it. This has been brought about either by an actual modification of nitrifying species, or by a gradual inurement to ammonium sulfate nitrogen by those nitrifying bacteria present from the first. It is at least worthy of note that on virgin Island soils organic forms of nitrogen are nitrified almost as readily as is sulfate nitrogen.

The subsoils, while lower, also do their best work with the nitrogen of ammonium sulfate.

Series III. Dried blood at the rate of 0.3 gram per culture (40.5 mgms. of nitrogen per 100 grains of soil) was here supplied as the source of nitrogen. This quantity of dried blood was used for two reasons (1 gram of this material per culture has heretofore ordinarily been supplied). It was desired here to compare, as nearly as possible, *equal* quantities of nitrogen (ammonia nitrogen and organic nitrogen), and W. P. Kelley * has recently shown that smaller quantities of blood nitrogen are not only more readily nitrified in soils, but also show slight differences in their nitrifying abilities to better advantage than do larger amounts.

A glance at Table XI shows blood nitrogen to be but poorly nitrified. This is especially true of the subsoils where, in three cases, there is a decided loss of nitrates showing active denitrification. Why the nitrification of ammonium sulfate should be good and that of dried blood the reverse is puzzling. As the latter must first be ammonified before it can be converted into nitrate, it might be argued that this first step is at fault, but the ammonification figures presented in Table X, while slightly below the average, would hardly bear out this contention, for, in the alkaline soils of the Kau District where the ammonification of blood nitrogen is *lowest*, we find its ***maximum nitrification***. Be that as it may, I should not argue for the application of dried blood nitrogen (which costs more than either nitrate or sulfate nitrogen) to these Hawaii soils. By comparing the "Averages for Hawaii" and the "Averages for the United States" at the foot of Table XI it will be seen that the soils of the two areas behave exactly oppositely. The soils of Hawaii convert twice as much ammonium sulfate nitrogen into nitrate as is the case with blood nitrogen, while of mainland soils (excepting in certain arid districts) the reverse is true.

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† See The Planters' Record for June, 1916, p. 369.

* See "Some Suggestions on Methods for the Study of Nitrification," Science, n.s., Vol. 43, pp. 30-33. Also, "Nitrification in Semiarid Soils—I," Jour. Agr. Research, Vol. VII, No. 10 (Dec. 4, 1916), pp. 417-437.

Series IV. As viewed from a practical standpoint, this is the *most important* series presented in Table XI. In this and in the remaining series the surface soils only were used. The same amounts of dried blood nitrogen were here added as in Series III, and besides this, enough lime carbonate (see Table VIII) to exactly neutralize each soil's acidity, the object being to note the effect of lime applications on nitrification (nitrogen availability). To state that the results are striking is to express it mildly. Let us compare the percentages of blood nitrogen transformed as given in column 9 with the percentages of blood nitrogen nitrified *where lime was added* as presented in column 11. In *all cases* liming increased nitrification; in 12 cases over 1½ times as much nitrate was produced; in 13 cases, over twice as much; in 2 cases, over three times as much; in one case, over four times as much, and in one case, 19 times as much. As an average for the entire Island, where dried blood is used alone, 29.0% of its nitrogen is nitrified; where dried blood plus lime is used 49.9% of the blood nitrogen is transformed. None of the materials hereafter described can be compared with lime as a stimulant for nitrification in these soils. If, by adding lime (the cheapest material which we apply to our soils), we can enhance nitrification two or three fold, the wisdom of such a procedure would be self-evident. But not only do we favor nitrification alone by so doing. We aid and increase *all* beneficial bacterial activity. We improve physical conditions. We contribute to a better physiological growth of the cane plant, and finally, due to all of these factors, increased yields are bound to result.

Series V. In this series the same amount of blood nitrogen was added as in Series III, plus 0.2 gram of gypsum (approximately 2 tons per acre).

It is a well known fact, both on the mainland and abroad, that gypsum as a rule tends to stimulate nitrification, and as one object of this work was to study nitrogen availability in these soils, it was thought worth while to here test out the effect of gypsum. Just how gypsum stimulates nitrification is not known unless it be in supplying calcium and sulfur in soluble forms, for the material is a neutral salt and has no power to correct soil acidity. A comparison of Series III with Series V shows that in these soils gypsum has little effect. Its use gives a slight increase in the Hilo-Puna District, but small decreases in the others. The average for all shows that, where dried blood is used alone, 29.0%

of its nitrogen is converted while, where blood plus gypsum is employed, 27.3% is nitrified. These findings corroborate results recently obtained at the Wisconsin Agricultural Experiment Station.* Several experiments there showed that, with the soils studied, the incorporation of calcium sulfate (gypsum) had no perceptible effect on the total numbers of bacteria growing on gelatine plates, nor on the production of ammonia or nitrates within those soils, while the addition of free sulfur considerably reduced nitrification. On the other hand, gypsum stimulated the growth of the nodule or legume bacteria.

Series V. Here the same amount of dried blood was again used as in Series III, plus 0.2 gram of reverted phosphate. In these high iron soils available phosphoric acid is often present in limited amounts. As the nitrifying bacteria use considerable quantities of this element in their life processes it was thought advisable to ascertain if, by any chance, the small amounts of readily available phosphoric acid present in a majority of these soils (see Table IV) could indirectly be limiting nitrate production. Besides the phosphoric acid in reverted phosphate there are also present considerable quantities of soluble calcium, but as Series V has shown, this element when in a neutral or acid salt has practically no effect on nitrification.† Thus any stimulation noted in this series is due, in large part at least, to the soluble phosphoric acid supplied.

A perusal of the results tabulated under Series VI shows that stimulation has accrued from the use of reverted phosphate. In but three instances, and these are in the Kohala District where large quantities of available phosphoric acid are found, does this material fail to give decidedly increased yields of nitrate. A comparison of the second columns of Series III and VI shows that, for all districts, reverted phosphate has increased nitrification. As an average for the entire Island, this material has increased the percentage of dried blood nitrogen nitrified from 29% to 38.8%.

Let us now briefly discuss the average nitrification results for each of the four districts. The original nitrate contents of the surface soils are all quite similar, requiring little comment.

Hilo-Puna District. Altho the soils here carry the largest amounts of total nitrogen, their abilities to transform it are the lowest (0.16%). Two causes are doubtless paramount; 1st., climatical conditions; 2nd., soil acidity. The excessive rains in this district coupled with impervious subsoil conditions in many cases (see page 58), militate against proper drainage, while the cold, damp weather at higher elevations tends, in addition, to depress nitrification. The optimum conditions of moisture and temperature at which the soil cultures are maintained in the laboratory probably contribute to higher results for all mauka soils and hence to a lessening of the differences which actually exist between mauka and makai soils in the field. This would be equally true for each district examined. That soil acidity also plays a leading part is shown by a comparison of the average percentages of blood nitrogen transformed (see averages for Series III and IV) with and without lime.

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* See "The Effect of Elemental Sulfur and of Calcium Sulfate on Certain of the Higher and Lower Forms of Plant Life," by W. Pitz, Journal of Agricultural Research, Vol. V, pp. 771-780 (1916).

† "Baker's C. P. Analyzed" dicalcium phosphate was used. It was acid to litmus.

Ammonium sulfate is nitrified in these soils with far greaater ease than blood. The averages for these two materials are 54.9% and 32.5% respectively.

Gypsum has but little effect on nitrogen transformation in this district. Reverted phosphate, on the other hand, increases it by 13.5%.

Hilo and Hamakua Coast District. Nitrification is here at its lowest ebb. This is especially true of the mauka soils. It will be remembered that, in this district, we find the most acid soils, which goes far toward explaining this untoward bacteriological condition.

Ammonium sulfate is here also nitrified with greater ease than dried blood.

Neutralizing soil acidity practically doubles nitrification as an average for the district, while in many cases it multiplies it by three and four. Applications of gypsum tend to lower nitrification, while little benefit accrues from the use of reverted phosphate. That *lack of lime* is here the chief factor limiting nitrogen availability cannot be disputed. In this district, *provided lime is not added,* nitrate of soda in small, regular applications is, I am convinced, the best form of nitrogen to apply. Exceptions to this statement may be made for certain of the less acid makai fields, but even here a mixture of nitrate and sulfate would probably give better results than applications of organic nitrogen other than green leguminous manures.

There are several cases in this district where, upon incubation, the mauka subsoils show a loss of original nitrate. The denitrifying bacteria in these soils have doubtless been fostered in the past by conditions which have benefited their growth and multiplication, i. e., poor aeration due to waterlogging, large amounts of organic matter, and liberal applications of nitrate of soda which, thru leaching, have readily found their way below.

Kohala District. These soils, both chemically and bacteriologically, are among the best on the Island. As will be remembered, the amounts of available mineral plant food in this district were second only to Kau. The same is true for nitrogen. Twenty-four percent of the nitrogen in dried blood was nitrified during the incubation period, while thirty-nine percent was the average for the district where ammonium sulfate nitrogen was supplied in equal amounts.

Upon neutralizing the soils with lime carbonate, approximately *twice* as much blood nitrogen was transformed. The addition of gypsum slightly depressed nitrification, while reverted phosphate had practically no effect. Here again *lime* is the soil amendment needed.

Kau District. The soils of this district may well be considered the best on Hawaii when viewed from either the physical, chemical or bacteriological standpoint. Climate here is doubtless the limiting factor in cane production. Nitrification is, in this area, at its best. Over 38% of the added blood nitrogen and nearly 63% of the sulfate nitrogen as averages for the entire district, were transformed during the month's incubation period.

In an endeavor to ascertain the effect on nitrification of lime applications to soils already plentifully supplied with this material and alkaline in reaction, applications at the rate of 2 tons per acre (0.2 gram per culture) were made to the soils of this district. The results appear under Series IV of this district. The alkaline soil No. 27A from the Hawi Mill and Plantation Company was also included in this test. *Without exception* nitrification is increased in already alkaline soils by further additions of lime carbonate. A reason for this is hard to find unless it be that lime applications here enhance physical conditions. I should not, however, advocate the use of lime on lands already well supplied, for without it, nitrification proceeds with sufficient rapidity to readily meet crop demands. Excessive nitrification often results in nitrogen losses.

Applications of gypsum to these soils slightly depress nitrification, while a considerable gain follows the addition of similar quantities of reverted phosphate. It will be recalled that the higher fields in Kau are not well supplied with available phosphoric acid.

Nitrogen Fixation. As has already been stated in Chapter 1, there are three large families (species) of soil bacteria whose mission is the fixation of free, atmospheric nitrogen.* These classes of bacteria are able to use gaseous nitrogen as food in much the same way as the higher plants, which, by means of the chlorophyll within their leaves, are able to assimulate and build the carbon dioxide gas of the air into the starches and sugars which go to make up their body substance. These three species of nitrogen fixing bacteria are; the *radicicola* species which live symbiotically in the nodules on the roots of leguminous plants; the *azotobacter* species which are free-living in the soil and derive the energy required for nitrogen assimulation from carbonaceous organic matter, and the *clostridium* species which are also free-living in the soil, but which prefer the more anaerobic subsoil conditions. This latter species also derives its energy from soil organic matter. The first two are by far the most important, the last named being very wasteful of carbohydrate materials oxidized per unit of nitrogen fixed.

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* There are several species of molds which are said to fix small amounts of free nitrogen, but the amounts so fixed are negligible when compared with the nitrogen fixed by bacteria.

See "Nitrogen Fixation by Yeasts and other Fungi," by Chas. B. Lipman, Jour. Biol. Chem., Vol. X, pp. 169-182.

That the growing of legumes is a practice to be fostered where possible will not be disputed, but there are good reasons why this practice cannot now be universally adopted on the plantations of these Islands with profit. It is thus the free-living, non-symbiotic nitrogen-fixing species of bacteria, living and functioning within our soils at all times where conditions are correct, which are of more importance to us at this time. Of these two species the more important *azotobacter* family will be here briefly discussed. Some ten different varieties of this species have so far been discovered. The nitrogen fixed by this class of micro-organisms is present in the bacterial cells as insoluble protein nitrogen (similar to the organic nitrogen of cotton seed meal). After the death of the cell the nitrogen so fixed is ammonified and nitrified in exactly the same way as other forms of organic nitrogen. There is one soil condition which is *absolutely imperative* to the fixation of nitrogen by this class of organisms. This is *lack of soil acidity*. Soils must be neutral or slightly alkaline for these bacteria to normally function. Knowing this fact, the writer tested four soils which he knew to contain the *azotobacter* species (numbers 8A, 22A, 24A and 15A) for nitrogen fixation by the "Beaker Method."† That these soils are acid is shown in Table VIII. With but one exception no nitrogen was fixed and here the amount accumulated was negligible. In fact a little nitrogen was *lost* in two instances. With this data at hand the following series of experiments were planned. In order to ascertain whether or not *azotobacter* were present in the several soils, they were (the surface soils only were used, as these organisms are seldom found in subsoils) first tested out in solution cultures.* In this method, exactly 1 gram of soil (whose nitrogen content is known, see Table III) was introduced into a known amount of the proper sterile nutrient solution and incubated 3 weeks at a temperature of 28° C. The presence of *azotobacter* is shown by a thin film or membrane which invariably forms on the surface of the solutions, and the amounts of nitrogen fixed are determined by analyses of the cultures for total nitrogen at the end of the incubation period. From these solution cultures were also isolated three different species of *azotobacter*§ which will be later described. All of the soils were now examined for nitrogen fixation by the standard "Beaker Method" (in which the soil itself, plus mannite as a source of energy, is used as the culture medium for its own contained bacteria) after *first exactly neutralizing* the acidity of each soil by the addition of the required amount of lime carbonate (see Table VIII).

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† See Appendix, p. 99.

* See Appendix, p. 98.

The following Table XII presents all of this data. The first column shows the soil numbers as well as the plantations from whence they came; the second column, the presence or absence of *azotobacter* species in these soils; the third, the amounts of nitrogen fixed per gram of mannite consumed, in solution cultures; and the last, the amounts of nitrogen fixed per grain of mannite in the soils themselves plus lime.

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§ For a detailed account of the more technical portions of this work, see "Azotobacter in Hawaiian Soils," by P. S. Burgess, in Soil Science, Vol. II, No. 2, pp. 183-192.

TABLE XII.

Nitrogen Fixation Results.

Soil Numbers		Presence of *Azotobacter*?	Solution Cultures. N. fixed per gram. of mannite. Mgms.	Soil Cultures (Beaker Method). N. fixed per gram of mannite. Mgms.
		Hilo-Puna District.		
Waiakea Mill Co.	1 A	absent [1]	2.03	1.20 [2]
	2 A	absent	0	5.60
	3 A	present	3.65	8.40
	4 A	present	7.55	5.60 [2]
Olaa S. Co.	36 A	absent	4.76	5.60
	37 A	absent	3.64	lost
	38 A	present	7.46	16.80 [2]
Average		43% present	4.15	6.17
		Hilo and Hamakua Coast District.		
Onomea S. Co.	5 A	absent	2.80	1.20 [2]
	6 A	present	3.75	11.20
	7 A	absent	3.20	11.20 [2]
	8 A	present	2.45	16.80
Pepeekeo S. Co.........	23 A	present	4.55	11.20
	24 A	absent	3.15	0
Kaiwiki S. Co..........	21 A	absent	3.85	0
	22 A	present	5.25	8.40
Hamakua M. Co.	18 A	present	4.80	2.80
	19 A	present	4.20	2.80 [2]
	20 A	present	3.85	8.40
Honokaa S. Co.	16 A	absent	3.85	4.60
	17 A	present	5.25	8.40
P. S. M.	14 A	absent	3.85	2.80
	15 A	present	6.51	5.60
Average		60% present	4.08	6.36
		Kohala District.		
Hawi M. & P. Co.	25 A	absent [1]	5.60	lost
	26 A	present	3.92	0
	27 A	present	11.06	16.80
	28 A	present	10.22	11.20
Kohala S. Co.	32 A	present [1]	8.82	5.60
	33 A	absent	5.46	2.80
	34 A	absent	5.18	5.60
	35 A	present [1]	7.00	19.60 [2]
Niulii M. & P. Co.	29 A	present	4.41	16.80
	30 A	present	7.70	11.20
	31 A	present	4.97	11.20
Average		72% present	6.75	9.16
		Kau District.		
Hawaiian Agr. Co.	9 A	present	7.70	11.20
	10 A	absent	0.84	1.20
	11 A	present	7.70	16.80
	12 A	absent	0	0
	13 A	present	3.29	5.60
Average		60% present	3.90	6.96

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[1] Much mold growth in culture.

[2] These figures may not be absolutely correct, as the very high amounts of original nitrogen in the soils rendered slight differences hard to detect. These analyses were made in tripliacte and the averages taken. This applies also to the total nitrogen figures as given in Table III.

The contents of this table should require but slight comment. The second column, disclosing either the presence or absence of this species of bacteria in these soils, is probably of more practical importance than the absolute amounts of nitrogen fixed by them under laboratory conditions, for we know that, if *azotobacter* are present, they can be induced to function if we provide suitable conditions for them, i. e. neutralize the acidity of the surface soils and provide organic matter. The high percentage of cultures showing the presence of *azotobacter* caused considerable surprise to the writer. This for two reasons, 1st., Hawaiian soils with which he had worked at the University of California were practically free from this species.* 2nd, Considering the high lime requirements of these soils, one would hardly expect to find *azotobacter* so plentifully distributed.

It will be noticed that, in all but two solution cultures, considerable quantities of nitrogen were fixed regardless of the presence or absence of *azotobacter.* In practically all cases however more nitrogen is fixed where this species is found. The ***clostridium*** species above mentioned together with certain molds which were noticed in a few of the cultures are probably responsible for the fixation where *azotobacter* is absent.

The last column of figures showing the amounts of nitrogen fixed in the soil cultures per unit of carbohydrate oxidized are open in a few instances to criticism (see footnote number two at the bottom of the table). As all will realize who have attempted to run total nitrogen determinations on soils high in this element, the comparatively small increases due to fixation are often very hard of accurate detection. For example, soil number 1A contains 102 milligrams of nitrogen per 10 grams of soil (the amount taken for analysis), and shows but 1.2 milligrams of nitrogen fixed per 50 grams of soil. Such differences are well within the limits of experimental error, and the final results cannot exact implicit confidence. Taken by and large, however, the figures in this column are as nearly correct as careful work can make them, and justify consideration.

The Kohala District again shows up well. Of the 11 samples drawn in this district but three were apparently entirely devoid of *azotobacter,* while the amounts of nitrogen fixed in the latter were high, showing the presence of other active fixing species.

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* See "Studies on Nitrogen Fixation and **Azotobacter** Forms in Soils of Foreign Countries," by C. B. Lipman and P. S. Burgess, Centbl. Bakt.. (etc.) abt. 2, Bd. 44, pp. 481-511.

The average amounts of nitrogen fixed for the several districts are well in accord with the results of similar studies which have been made by the writer and by others on mainland soils of good fertility, but it must not be forgotten that practically no fixation was here obtained until these soils had been neutralized with lime carbonate.

Pure Culture Work. As was stated above, three different species of *azotobacter* were isolated from the mixed solution cultures, by plating out on mannite agar. Two of these were readily identified as *Azotobacter chroococcum* (isolated from culture No. 11A) and *Azotobacter vinelandii* (isolated from culture No. 20). The remaining organism (isolated from culture No. 23A) was very similar to *A. vinelandii* in morphology and cultural characteristics with the following few exceptions. The individual cells were smaller, altho of similar shape. There was no tendency to form a colored pigment; even on old mannite agar slants the growth remained white, there being no yellow or orange tint observed. This form is probably a variety of *A. vinelandii,** and, from a study of the solution cultures, is quite widely distributed in the soils of this Island.

These three species of *azotobacter* were now examined as to their abilities to fix nitrogen in pure cultures, both in solutions and in soils. Bacterial suspensions of these organisms were made from young mannite agar slants (3 to 4 days old). This was done by pouring 10 c. c. of sterile tap water over the growth on the slant and working up the suspension with a sterile platinum needle. All were cloudy in appearance. Amounts of 1 c.c. each were used to inoculate 100 c.c. portions of sterile, nutrient mannite solution in 500 c.c. flasks. Other 1 c.c. portions were used to inoculate 100 gram portions of the station soil in covered tumblers which had previously been sterilized for 3 hours at 15 lbs. steam pressure and had each received 2 grams of mannite after being cooled. The solution cultures only were run in duplicate. After a 3 weeks incubation period at 28° C., total nitrogen determinations were made. The results are set forth in Table XIII, which follows.

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* A culture of this organism has been sent to Dr. J. G. Lipman of the New Jersey Station for identification.

TABLE XIII.

Nitrogen Fixed by Pure Cultures of *Azotobacter* Isolated from Hawaii Soils.

Organism.	Solution Cultures. N fixed per gram of mannite. Mgms.	Soil Cultures. N fixed per gram of mannite. Mgms.
A. chroococcum, var. ...	4.62	5.00
A. vinelandii, var.	8.57	5.00
A. vinelandii, n. var.? ...	5.80	8.75

As a rule, more nitrogen is fixed by all species of *azotobacter* in soil cultures than in solutions. The behavior of organism number two is here hard of explanation, but as the work was repeated, its correctness cannot be questioned. Whether the soil used suffered so serious a change during sterilization as to render it unfit for the growth of this microorganism, or whether physiologically it works to better advantage in solution, are questions which cannot now be answered. The pure cultures in solutions all gave beautiful surface membraneous growths. The first was light brown in color; the second greenish orange, and the third glistening white.

It may be mentioned in passing that a mixed culture of the first two organisms listed in Table XIII are the nitrogen fixing bacteria used in the preparation of the "Bacterized Press Cake" which is at present receiving attention both here at the Experiment Station and elsewhere on certain of the plantations.

Remembering that the Hawaiian Islands are young, geologically speaking, and further that the nearest land area of any extent is over 2,000 miles distant, it might at first seem rather hard to account for the prevalence of *azotobacter* species in these soils. (Nitrogen fixing bacteria, both *azotobacter* and *radicicola,* are usually among the last bacterial species to make their appearance in new soils). There are, however, several ways of accounting for their possible introduction and distribution. Thousands of tons of commercial fertilizers are received from the coast and applied to our soils each year. Fine soil and other cheap materials are sometimes used as "fillers" in these "mixed goods," and, as this material is never sterilized, it is conceivable that it might carry *azotobacter* species. Dried blood, tankage and guano are also shipped here in considerable quantity, which may also be infected with these microorganisms. During recent years green manuring with legumes has found favor on several of the plantations. The legume seed, which has been imported from various parts of the world, doubtless harbors large numbers of bacteria.

Be that as it may, we are sure of one fact: *azotobacter* are widely distributed in Hawaiian soils.

CHAPTER VI.

GENERAL SUMMARY.

A brief resumé of the more important facts, as disclosed by a study of the data heretofore presented in this bulletin, follows.*

1. The first chapter presents a general discussion of soils; their formation; mineralogical and chemical composition, and their more important physical, chemical and biological properties.
2. The Hawaiian Islands are all of volcanic origin, and, except insignificant coral formations, are composed almost entirely of basaltic lavas which differ very little, chemically, from those of other volcanic regions. The resulting soils are chiefly laterites, very high in iron, aluminum and the alkaline earths, but low in silica. Due to pre-existing tropical verdure most of the soils contain large amounts of humus and nitrogen. Total phosphoric acid and *soluble* silica are also usually high. Physically, most of the soils would be classed as clay or silty clay loams of high organic matter content. The soils, altho differing considerably among themselves, are slightly below the average for humid mainland soils when considered from the biological standpoint.
3. Hawaii is the largest and geologically the most recent of the Hawaiian Islands. Its climatical conditions vary greatly (both rainfall and temperature).

From its ports about 35% of the sugar crop of the Islands is exported each year. There are four large cane growing districts on this island within each of which the soils are similar but which differ considerably the one from the other. These are the Hilo-Puna District, the Hilo and Hamakua Coast District, the Kohala District and the Kau District (see frontispiece map). The plantations in all districts border the sea at their lower levels (there are two or three exceptions), running back and upward toward the high interior of the island. The surface soils of the lower fields are usually from 12 to 18 inches deep while those at the higher altitudes vary from 4 to 7 inches. In drawing the soil samples for this work it has been the writer's object to secure representative samples from the different altitudes as well as from several of the plantations in different localities in each district. The method of collecting and preparing the samples is given. Each is also located and briefly described.

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* It is hoped that it will not be the purpose of the reader to let the few words here appended take the place of a more critical reading of the preceding pages, for but a very cursory and superficial summary can be given where such a volume of data is tersely reviewed.

4. Physically the soils of Hawaii are unique. They would in large part be classed as high humus clay and silty clay loams altho the amounts of true clay (hydrated aluminum silicates) in all cases are very low or nil. Colloidal aluminum and iron hydrated oxides give to the soils their apparent clayey characteristics. A fairly complete discussion of soil moisture in connection with these soils is given. As would be expected, all of the moisture coefficients are abnormally high. The hygroscopic coefficients vary from 9 to over 26% when determined by Hilgard's standard method, while the optimum moisture capacity averages about 45% of the dry weight of the soils. The "free water" varies from 15 to 38% while the maximum moisture holding capacity is in all cases well above that for average mainland soils. These soils do not usually cake badly unless thoroughly puddled. When worked under optimum conditions they are fluffy and show good tilth. The heavier soils are in the Hilo and Hamakua Coast District followed by the silty clay loams of Kohala and the silty and sandy loams of Kau. In the Hilo District we find chiefly high humus and muck soils.

5. The chemical work is divided into three parts: the plant food work; the soil acidity work, and the alkali work. Under each heading will be found a discussion of the soils of each district.

Taken by and large, the following conclusions may be drawn from the plant food work.† The soils, with but few exceptions, are high in total nitrogen but its availability is universally low. The same is more or less true of phosphoric acid. Potash, both total and available, is high in all of the soils examined except in those of the Hilo District. Here potash fertilization would doubtless be found profitable. The amounts of total and available soil potash follow with surprising regularity the amounts of total potash as determined in the final molasses and in the molasses ashes from the mills of the several plantations. The total lime figures vary from over 5% in the alkaline Kau soils to less than 0.2% in acid Hamakua. A discussion of available plant food as found on analysis, together with the amounts necessary for the production of a good cane crop, appear in some detail.

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† The standard "Agricultural Method" of the Association of Official Agricultural Chemists and Dyer's 1% citric acid method (both modified, see Appendix) were used in this work.

A few words on lime and liming proceed the important experimental work along this line. All of the mauka soils and most of the makai fields are *acid*.

The lime requirements for the *surface* soils vary from 1 ton of calcium carbonate to 11 tons depending on location. Table VIII presents these figures for all of the plantations investigated. giving the amounts of lime (as burned lime, hydrated lime and carbonate of lime) necessary to neutralize both the surface and subsoils. We advocate the use of lime in carbonate form.

The amounts of alkali salts (the chlorides, carbonates and sulfates of sodium) are in all cases negligible.

6. All of the surface soils are fair ammonifiers. The amounts of ammonia produced are not large but I consider them sufficient providing nitrification keeps pace.

7. A thorough study was made of nitrification in Hawaii soils (see Table XI). Six series of experiments were carried out. In the first, the soils received no additions of nitrogen but were incubated under standard conditions of moisture and temperature to ascertain the nitrifiability of their own organic nitrogen. In the second, ammonium surfate was added; in the third, dried blood; in the fourth, dried blood plus sufficient calcium carbonate to exactly neutralize acidity; in the fifth, dried blood plus gypsum, and in the sixth, dried blood plus reverted phosphate. The results may be briefly stated as follows: Considering the large quantities of total nitrogen which these soils contain, the absolute amounts and the percentages of it nitrified are *very low*. Ammonium sulfate nitrogen is nitrified approximately twice as fast as dried blood nitrogen. As an average for the soils of the entire island, the addition of lime *doubles* the nitrification of dried blood. In some instances it multiplies it by three and four. Gypsum has practically no effect upon nitrification in these soils. In some instances a loss is recorded. Reverted phosphate increases nitrification by approximately 35%.

8. Nitrogen fixation as determined both by solution and by soil culture methods is fair in Hawaii soils. *Azotobacter* forms are well distributed (see Table XII). Three different species (*A. chroococcum*, *A. vinelandii* and *A. vinelandii, n. sp.*?) were isolated in pure cultures, described and tested for nitrogen fixation in both solutions and soils.

9. In the Appendix which follows is given a full discussion of methods used in the pursuance of these studies.

ACKNOWLEDGMENTS.

The author here takes pleasure in acknowledging his indebtedness to Mr. H. P. Agee for many valuable suggestions rendered during the progress of the work; to Mr. George Hutchinson for assistance in certain of the analytical operations; to Mr. W. R. R. Potter who kindly supplied the frontispiece map, and to all of the plantation managers and overseers who so kindly assisted in the taking of soil samples and in the furnishing of necessary data concerned therewith.

APPENDIX.

DISCUSSION OF ANALYTICAL METHODS EMPLOYED.

(a) SOIL PHYSICS.

Hilgard's Method for Maximum Moisture Holding Capacity.

Hilgard's water retention soil cups as purchased from the Central Scientific Company of Chicago, were used in making these determinations. They are small brass cups 2 inches in diameter by ⅞ inch deep, the bottoms of which are perforated metal diaphragms fastened one centimeter from the top. Thus, when filled, each carries a layer of soil 1 cm. thick which Hilgard fixed as his standard for this determination. The cups are numbered and their weights, to 0.1 gram, are known. In making the determination a piece of thin filter paper of proper size is first fitted over the perforated bottom of a cup which is then filled with soil, (previously passed thru a 3 mm. sieve to remove the coarser particles), finally "striking" the surface level with a thin spatula blade. The cup plus soil is now placed in water* so that the perforated bottom is just in contact with its surface. By capillarity, the water almost immediately appears at the soil surface.

The cup of soil is allowed to remain in contact with the water surface for 1 hour when it is quickly removed, wiped off, and weighed. After completely drying out in an oven at 102° C. the cup plus soil is again weighed. The difference gives the amount of moisture absorbed, which, divided by the weight of water free soil (found by subtracting the weight of the soil cup from the second weighing), gives the soil's maximum moisture holding capacity.

(Read Hilgard's "Soils," pages 207 to 210; also Circular No. 6, California Agr. Exp. Sta., page 15).

Hilgard's Method for the Determination of Hygroscopic Soil Moisture.

Hilgard's "Moisture Absorption Apparatus," as sold by the Central Scientific Company of Chicago was used in making the hygroscopic determinations, and the method as outlined in his book, "Soils," pages 196 to 201, followed, with one or two minor changes.

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* Where large numbers of determinations are to be made, photographers' trays will give good service as water reservoirs.

About ten grams of the soil to be tested are carefully sifted from a 1 mm. sieve into each of the flat soil pans, the object being to deposit a layer not over 1 mm. deep over the entire pan bottom The pans are then placed in the moist chamber (which in this work is kept at 25° C. and completely saturated) for from 20 to 22 hours. A long series of tests convinced us that shorter periods gave incomplete saturation, while longer ones occasionally invited dew-formation or condensation on the soil surface. At the end of the exposure period each soil is quickly poured from its pan into an accurately tared weighing bottle, stoppered and weighed. The stopper is then removed and the soil completely dried in an air bath at 110° C. The weight of the water absorbed, divided by the amount of dry soil taken, gives the soil's hygroscopic coefficient, or the amount of moisture which that soil can absorb from a saturated atmosphere at a temperature of 25° C. (See circular No. 6, California Agr. Exp. Sta., page 17.)

(b) SOIL CHEMISTRY.

Total Acid Soluble Mineral Plant Foods (Agricultural Method.)†

As these peculiar Island soils have necessitated a few diviations from the original method appearing in the U. S. D. A., Bu. Chem., Bul. 107, it was thought worth while to here briefly insert the modified procedure.

Digest 5 grams of soil for 10 hours in a 150 cc. porcelain soil digestion cup with 50 cc. hydrochloric acid (sp. gr. 1.115) on a boiling water bath. Dilute with about 50 cc. of hot water, and filter hot into a 250 cc. volumetric flask, washing residue to volume. Cool and make up to volume. (Sol. A.) Do not dehydrate residue.

Insoluble Residue and Soluble Silica.

These are determined as in Hilgard's Method, California Agricultural Experiment Station, Circular No. 6, page 18.

Iron, Aluminum and Titanium.

To 50 cc. of solution A add 3 cc. of nitric acid, make up to at least 300 cc. (to avoid manganese later precipitating out), and boil 20 minutes. Cool slightly, make alkaline with ammonia, and boil off excess. Filter, wash with hot water and transfer precipitate to original beaker. Redissolve in dil. hydrochloric acid and reprecipitate as before, washing free from chlorides. Ignite and weigh as ferric oxide, aluminic oxide, titanium oxide and phosphorus pentoxide. Reserve filtrate (sol. B) for determining manganese, calcium and magnesium.

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† Also see Annual Report of the Hawaii Experiment Station (U. S.) for 1915, pp. 34-36.

Treat a second aloquot of 50 cc. (sol. A) as above but instead of igniting the precipitate redissolve in dilute sulfuric acid (boiling), cool and make up to exactly 100 cc. Determine iron by titrating 25 cc. of this solution with $\frac{N}{10}$ potassium permanganate in the usual way. Determine titanium by taking 5cc. of the sulfuric acid solution, diluting to 90 cc., adding 5 cc. of dilute sulfuric acid and 5 cc. of 4% hydrogen peroxide solution, mixing well, and comparing in a Sargent-Kennicott colorimeter with a standard solution of titanium sulfate prepared at the same time.

Reserve filtrate from this second iron precipitation for the determination of sulfates, soda and potash (sol C). As potassium permanganate oxidizes titanium as well as iron, the proper correction in the volume of this solution must be made in calculating the iron. As usual, the alumina is determined by difference.

Manganese.

Concentrate sol. B to 150 cc., add 3 cc. pure bromine (undiluted), let stand a few minutes, make decidedly alkaline with ammonia and boil. Let stand to cold, filter, ignite and weigh as the brown oxide (Mn_3O_4).

Calcium.

Evaporate the filtrate to dryness and completely and carefully volatilize the ammonia salts. (This is necessary to totally eliminate unprecipitated traces of manganese). Take up in dilute hydrochloric acid and determine calcium as the oxalate in the usual way.

Magnesium.

Magnesium is determined in the lime filtrate in the regular way.

Sulfates.

Best results are obtained in these high iron soils by removing iron and aluminum previous to the precipitation of sulfates. Sol. C is evaporated to dryness and the ammonia salts removed. The residue is taken up in dil. hydrochloric acid and sulfates determined gravimetrically after precipitating with barium chloride.

Potash and Soda.

These determinations are made according to the Official Methods (Bul 107, Bureau of Chem., U. S. D. A.) without change.

Phosphoric Acid.*

To 50 cc. of the original solution (A) add a few drops of nitric acid, boil a few minutes, make alkaline with ammonia, boil off excess, filter and wash with hot water.

Transfer precipitate to original beaker and dissolve in a small volume of hot, dilute nitric acid. *Nearly* neutralize with ammonia and add 25 to 50 cc. of ammonium molybdate solution after bringing to a temperature of 60° C. on a water bath. From here proceed as in Official Methods.

In most of the work reported in this bulletin, the lime, potash and phosphoric acid only were determined. The digestion was made as above, as was the phosphoric acid determination. The lime was directly determined in the first iron filtrate after removing manganese while, after removing resulting ammonia salts, the potash was obtained. The method of determination in each case was as above outlined.

Total Nitrogen in Soils.

The Gunning Method as modified by Hibbard was here used (see Jour. Ind. and Eng. Chem., Vol. 2, pages 463 to 466). Ten grams of dry soil were used in each determination, which had previously been *finely ground and sifted.* This latter precaution is absolutely necessary where over 0.4 or 0.5% nitrogen is present. Otherwise closely agreeing duplicate determinations cannot be obtained. It was also usually found necessary to add 50 instead of 30 cc. of concentrated sulfuric acid. The standard amounts of salts added were not increased. Lacmoid was used as the indicator in titrating.

Citrate Soluble Mineral Plant Foods.

Dyer's original method, which appeared in the Journal of the Chemical Society (London), Vol. 65, pages 115 to 167, calls for the intermittent shaking of the 1% citric acid plus soil over a period of 7 days at room temperature. I have found, however, that when this procedure is followed in this warm climate, much mold and bacterial growth is very apt to occur in these solutions, which would have a tendency to vitiate the final results obtained. Further, in the method as originally proposed, different portions of the original solution are used for the separate determinations (phosphoric acid, potash and lime), thus necessitating the use of a large initial volume of the citric acid solution and several tedious evaporations of the separate portions of solution to dryness. For these reasons, modifications have been introduced which have saved much time while in no way impairing accuracy. The modified method as used in our laboratory follows:

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* See Hawaii Agr. Exp. Sta. Bul. 41, Appendix.

Place 100 grams of the air-dried soil sample in a Winchester acid bottle. Add 1 liter of a 1% citric acid solution. Shake in a shaking machine 6 hours. Let stand 24 hours to clear. Siphon off about 700 c.c. of the clear supernatant liquid and filter it through a double filter paper. Evaporate exactly 500 c.c. *nearly* to dryness in a 600 c.c. beaker on the hot plate, then transfer the resulting dark colored solution to a platinum dish (using hot water) and evaporate to dryness on a water bath. Completely dry the sticky residue (2 hours in a hot air oven at a temperature of about 120° C.). Ignite the residue in the platinum dish in a muffle at a low temperature (dull redness) for about 2 hours to remove organic matter. The char should now be gray in color. Moisten with con. HCl, add a little hot water and evaporate to dryness on the water bath. Leave on water bath at least 1 hour to dehydrate any silicic acid still remaining as such. Take up in a little con. HCl; add a little water; heat ½ hour on the water bath; add more hot water and filter. Wash five times with hot water slightly acidified with HCl; make up to at least 300 c.c. with hot water. To the clear filtrate add 2 or 3 c.c. of con. HNO_3 and boil 15 or 20 minutes to oxidize all organic matter in solution. Precipitate Fe, Al, Ti and P_2O_5, with NH_4OH in hot solution, filter and wash free from chlorides with hot water. In case of insufficient Fe to color the precipitate slightly brown, add a few c.c. of a 10% $FeCl_3$ solution before precipitation. (This is to insure complete precipitation of P_2O_5.)

Phosphoric Acid (P_2O_5).

Dissolve the above precipitate in dilute HNO_3 and boil. Cool slightly, *nearly* neutralize with NH_4OH, add 5 grams of NH_4NO_3 (C.P.) and precipitate P_2O_5 with 25 c.c. of molybdate solution at 65° C. Let stand 20 minutes at 65° then let cool. Filter through asbestos, *thoroughly* wash and determine P_2O_5 volumetrically.

Lime (CaO).

Evaporate down to 150 c.c. the filtrate from Fe and Al, make very slightly alkaline with NH_4OH, and precipitate Ca as the oxalate with ammonium oxalate solution, hot. Let stand on the water bath 1 hour, then cold over night. Filter, wash with cold water, dissolve in H_2SO_4 (1 to 5 by volume) and titrate with a standard $KMnO_4$ solution.

Potash (K_2O).

Acidify filtrate from Ca slightly with dil. H_2SO_4. Evaporate nearly to dryness in beaker, transfer to platinum dish and run to dryness. *Carefully* ignite off excess of H_2SO_4 and *all* ammonium salts over free flame; take up residue in hot water; filter into white porcelain evaporating dish and add 2 or 3 drops of dilute HCl and sufficient platinic chloride solution to precipitate all of the potassium. Evaporate *nearly* to dryness, filter, wash and weigh as potassium platinic chlorid in the usual gravimetric way.

Several experiments were performed to ascertain the correct length of time of continuous shaking with the citric acid solution, for it is evident that the final results obtained must be identical with those found where the 7-day period of intermittent shaking is used. The following Table shows the percentages of phosphoric acid and potash in two typical Island soils, as determined by Dyer's original method, together with those as obtained with the modified method where different lengths of time of shaking were employed. In following out the former procedure, about 2 c.c. of a 40% formalin solution were added to the solutions in each shaking bottle to avoid so far as possible the growth of molds and bacteria therein.

Percentage of phosphoric Acid and Potash Extracted from Typical Island Soils by Dyer's Original Method and by the "Modified Method."

	Dyer's Original Method	Modified Method, Times of Shaking			
		3 hours	6 hours	9 hours	12 hours
Soil I, P_2O_5....	0.0070	0.0052	0.0068	0.0068	.0068
Soil 1, K_2O....	0.0320	0.0300	0.0315	.....	....
Soil II, P_2O_5....	0.0042	0.0040	0.0033	0.0041	.0044
Soil II, K_2O....	0.0326	0.0294	0.0330	.....	....

Soil I came from the Station grounds and Soil II was obtained from the middle fields of the Oahu Sugar Company. The potash figures for the 9 and 12-hour periods of shaking were not determined. The potash is apparently more readily dissolved from the soils tested than is the case with the phosphoric acid. A study of the above table will show 6 hours' shaking to give results well in accord with those of Dyer's original method. This period was therefore adopted.

NOTE.—The method above outlined for the determination of citrate soluble plant foods is not applicable to high manganese (above about 1% Mn_3O_4) soils. Here separate aliquots for phosphoric acid and potash must be taken, and several changes from the above method made. A complete discussion of this modified method is soon to appear.

Total Potash in Molasses (or Other Organic Material).

To about 5 grams of molasses (accurately weighed) in a tared platinum dish add 15 cc. of approximately 1 to 2 sulfuric acid. Stir thoroughly and evaporate to dryness on the water bath. Over a free flame carefully drive off the remaining water, and, in a muffle at a low red heat, burn to a white or grey ash. Add about 20 cc. of hot water and 5 cc. hydrochloric acid. Let stand a half hour on a hot water bath, add more water and make up to 250 cc. in a volumetric flask, after cooling. Filter. To 50 cc. of the clear filtrate add a few drops of nitric acid and boil. Precipitate iron, aluminum and calcium with ammonia and ammonium oxalate together. Filter and wash. Discard the precipitate. To the filtrate add about 3 cc. of concentrated sulfuric acid and evaporate to dryness in a thin porcelain evaporating dish. Carefully drive off excess of sulfuric acd and ammonium salts over a free flame. Take up residue in hot water, filter into a clean porcelain evaporating dish; wash residue thoroughly; add 3 drops of dilute hydrochloric acid to the filtrate and precipitate the potash with plantinic chloride solution. Evaporate *almost* to dryness on the water bath, cool, take up in 80% alcohol and determine the potash gravimetrically in the usual way.

*Soil Acidity (Modified Veitch Method).**

Qualitative test. Ten grams of dry soil are weighed out into a 250 cc. *Jena* glass beaker and stirred thoroughly with 50 cc. of neutral distilled water. Evaporate to dryness on a water bath, removing as soon as dry. Add 100 cc. of neutral distilled water, and rotate the beaker in such a manner as to stir and dislodge all adhering soil particles from sides and bottom. This is done twice at intervals of 30 minutes each. Let stand to clear (over night) and carefully pipette off 50 cc. of the supernatent liquid into a 100 cc. Jena beaker. Boil down on a hot plate to 5 cc. add 3 drops of neutral phenolphthalein and note any color change. No color indicates an acid soil; very slight pink, a neutral soil, and a decided red an alkaline one. In case the soil is *acid,* proceed as follows:

Quantitative determination. Proceed as above in weighing out samples and adding 50 cc. of water. Then add progressive, known amounts of standardized lime water solution (1 cc.=1 mg. CaO), evaporating to dryness, taking up in 100 cc. water, and noting the final color with phenolphthalein, as above. The procedure is repeated with the varying amounts of lime water until a point is reached where a color change, from colorless to slight pink, is obtained upon the addition of 1 *cc.* of the stand lime water solution. This is the end point. The number of cc. (milligrams of CaO) required is calculated, and this multiplied by 100 and divided by the weight of soil used (10) gives the percentage of acidity in the soil under analysis; differently stated it is the percentage of CaO (lime oxide) which must be added to the soil to produce neutrality. This multiplied by 3,000,000 lbs. (the weight of an acre-foot of average Hawaiian soil) shows the number of pounds of lime oxide to apply per acre. If lime carbonate is to be used, this figure multiplied by the factor 1.78 and divided by 2,000 gives tons per acre of this material to add.

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* Also see Annual Report 1912-13, Penn. Agr. Exp. Sta., pp. 50-52.

In order to obtain accurate concordant results it is necessary that each step in the procedure be exactly duplicated from day to day. The possibilities and limitations of this method have often been fully discussed in other papers and will not here be further emphasized.

*The Determination of the Alkali Salts.**

The equivalent of fifty grams of the *dry* soil are placed in a quart Mason jar, 500 cc. of freshly-boiled distilled water added, and the whole shaken for 3 hours in a shaking machine. Two hundred fifty (or more) cc. of the solution is filtered through an unglazed porcelain pressure filter and 125 cc. (representing 12½ grams of soil) titrated directly for chlorides, as in the Hilgard Method. Another 125 cc. portion is placed in a porcelain evaporating dish and evaporated nearly, but not quite, to dryness on a water bath. The resulting residue and solution is then treated with successive small portions of 50% alcohol (which does not dissolve calcium carbonate). These alcohol extracts are then filtered to remove any $CaCO_3$, the filtrate made up to 200 cc. with distilled water, a few drops of methol orange added, and titrated against a standard acid solution $\left[\frac{N}{100}\right]$ for the sodium carbonate and bi-carbonate. By consulting a table of chemical solubilities, or by actual trial, it will be found that calcium carbonate in the form of coral sand or coral rock (the only forms of calcium carbonate found on these islands) when present in soils, are soluble to the extent of about 3 or 4 milligrams in the 125 cc. of water used. This would neutralize from 6 to 8 cc. of the $\frac{N}{100}$ HCl used in the titration. For this reason the procedure using 50% alcohol, which at most dissolves but traces of the $CaCO_3$, was adopted. The following precautions should be observed: Commercial 95% alcohol may be slightly acid. This must be corrected before use. The hood where the solutions are evaporated to dryness must be free from acid fumes.

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* The "New Method" as recently perfected in this laboratory for the determination of chlorides and carbonates of sodium.

(c) SOIL BACTERIOLOGY.

Ammonification ("Beaker Method").

Fifty gram portions, either in duplicate or in triplicate, of the air dried soil to be tested are weighed out into sterilized glass tumblers and exactly one gram of dried blood of known nitrogen content added. This is thoroughly mixed in with a sterilized spatula. Add sterile distilled water to bring the moisture content of the soil up to the optimum, let stand an hour or two to equalize moisture conditions, and again stir. Cover the tumblers with Petri dish covers and incubate 7 days at 28° C. Transfer the soils to copper distilling flasks, add 10 grams of light magnesium oxide and 500 cc. of distilled water, and distill off the ammonia (formed in the soil from the dried blood nitrogen) into standard acid, titrating in the usual way. A small piece of zinc or paraffine should be added to the soil mixture to prevent "bumping" during distillation.

Fifty grams of the original soil (without incubation) should also be run for ammonia (blank) and this subtracted from the average culture result. Finally calculate the percentage of original blood nitrogen which has been changed to ammonia nitrogen in the soils during the incubation period. (Read, "Ammonification in Soils and in Solutions," by F. L. Stevens and W. A. Withers, Cent. Bakt. (etc.), Vol. 23, p. 776).

Nitrification ("Beaker Method").

Weight out four 100 gram portions of air dry soil into clean, sterile glass tumblers. Treat each as follows:

No. 1—Blank (nothing added).
No. 2—Blank (add water only, and incubate).
No. 3—Add 0.2 gram ammonium sulfate (42.4 mgs. N).
No. 4—Add 0.3 gram dried blood (40.5 mgs. N).

(Weight out other 100 gram portions of the soil in case other nitrogenous materials are to be tested).

Thoroughly mix each with a sterile spatula. Add optimum amounts of sterile distilled water to all calutures except No. 1, and incubate 4 weeks at 28° C. after covering with Petri dish tops. About 3 cc. of sterile water must be added to each culture each week (except No. 1) to make up for loss by evaporation.

At the end of the incubation period, remove the covers and dry the cultures in a hot-air oven at 100° C. (not higher or a loss of nitrates results). Place each culture in a 500 cc. shaker bottle and add 2 grams of calcium carbonate to each to floculate the clay. Add exactly 250 cc. of distilled water to each and shake every few minutes for an hour. Let settle and filter thru paper. Take exactly 25 cc. of the clear filtrates and determine nitrates present by the modified Phenoldisulfonic Acid Method of Gill. (See "Soil Bacteriological Laboratory Manual," Pub. by Chemical Pub. Co., Easton, Pa., by P. S. Burgess, pages 103 to 105).

Subtract the nitrate nitrogen found in No. 1 (blank) from the others, and express both as milligrams of nitrate nitrogen formed per 100 grams of soil and also (knowing the nitrogen content of the materials added) as percentage of original nitrogen nitrified.

(Read, "Ammonification and Nitrification in Soil and in Solution," by F. Löhnis and H. H. Green, Centbl. Bakt. (etc.), Vol. 40 p. 457. "Nitrification in Soils and in Solutions," by Stevens and Withers, Centbl. Bakt. (etc.), Vol. 23, pp. 355-373 and 776-785).

Nitrogen Fixation in Solution.

Make up the following nutrient solution::
In 1 liter of tap water dissolve,

0.2 gram K_2HPO_4
0.2 " $MgSO_4$
0.5 " NaCl
20.0 " mannite
1 drop of a 10% $FeCl_3$ solution.

Add a few drops of phenolphathalein and just neutralize with a 1% solution of KOH. Place 100 cc. of this solution in 500 cc. Erlenmeyer flasks, plug with cotton and sterilize in an antoclave at ten pounds steam pressure for ten minutes. When cool, inoculate each flask with exactly 1 gram of the soils (whose total nitrogen contents are known) to be examined. At the end of a 3 weeks incubation period, at 28° C., transfer the contents of each flask to a glass Kjeldahl flask, digest and determine total nitrogen as above. Attention will be required during digestion on the furnace to prevent frothing, caused by the excess of carbon added in the mannite which the bacteria have not completely oxidized.

The difference between the amounts of nitrogen in the 1 gram portion of soil added as an inoculum, and the amounts of nitrogen finally found in the cultures, divided by two, gives the quantities of nitrogen fixed per gram of mannite consumed.

For methods of isolating pure cultures of *azotobacter* from these mixed solution cultures, see "Soil Bacteriology Laboratory Manuel," (Chemical Pub. Co., Easton, Pa.), by P. S. Burgess, pages 50-51.

Non-Symbolic Nitrogen Fixation ("Beaker Method").

Weigh out into sterile glass tumblers 50 gram portions of the soils to be tested. Add exactly one gram of mannite to each and sterile tap water to optimum moisture contents. Let stand an hour or two and mix each thoroughly with a sterilized spatula. Cover with Petri dish tops and incubate 3 weeks at 28° C., adding 2 cc. of sterile water each week to make up for evaporation. At the end of the incubation period dry out the cultures in a hot air oven at 100° C., grind in a mortar and carefully weigh out 10 gram portions of each culture in duplicate into Kjeldahl flasks. Determine the total nitrogen present by the modified Gunning Method as given above (page . .). The difference between the amount of nitrogen found in the culture and in the original soil before incubation, represents the amount fixed (10 grams of soil being taken for analysis in each case). This amount (in milligrams) multiplied by 5 gives the quantity of atmospheric nitrogen fixed per gram of mannite consumed.